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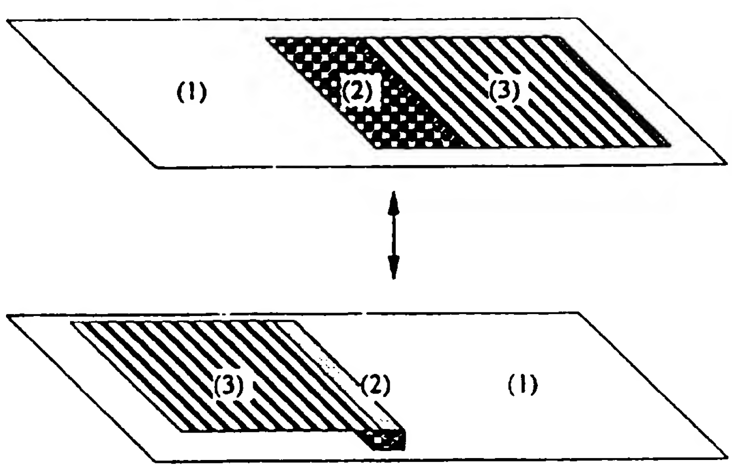

(57) Abstract

A micromachined structure which comprises one or more bi- or multi-layer hinges and one or more rigid components, the hinges serving to move and/or position the rigid component(s) by bending under the influence of one or more stimulus/stimuli. In a preferred embodiment, the hinges are flexible, offering a large degree of bending, and are small in size compared with the area of the rigid components. In a further preferred embodiment, the hinges are used to fold together the rigid components into predetemined three-dimensional structures and/or to achieve three-dimensional positioning of one or more rigid components. In a further preferred embodiment, the bending of the hinges can be continuously controlled between the minimum and maximum degree of bending. In a further preferred embodiment, the hinges comprise an organic layer such as a conducting polymer.

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A MICROMACHINED STRUCTURE AND USE THEREOF, AND A MICROMACHINED DEVICE AND A METHOD FOR THE MANUFACTURE THEREOF

Technical Field

This invention relates to micromachined structures (micromachines). The invention is specifically a microactuator, or a small moving part, that consists of one or more active, bending hinges connecting one or more rigid components. More specifically, the bending of the hinges is controlled electrically or with some other stimulus and said bending results in a change in the spatial or angular position of non-bending elements, referred to as essentially rigid components.

Background art and disclosure of the invention.

In the following, reference will be made i.a. to the list of prior-art references Refs 1-32 on pages 28-32. These references are hereby incorporated by reference.

One of the goals of present day technology is to manipulate ever smaller objects, to work within increasingly smaller dimensions. This is desirable in many instances for a variety of reasons. One is to improve health care by increasing what can be done with non-invasive surgery: one would like the ability to do things such as perform surgery in the smallest blood vessels of the heart or make connections between electrical devices and damaged neurons. Another is to improve diagnostic testing: for instance, it is necessary to take as little blood as possible when doing allergy testing on newborn babies, so a way to handle and diagnose very small volumes of fluid is needed. Another example of handling small objects is single cell manipulation, for example for in vitro fertilization of eggs or for sorting cancerous from non-cancerous cells. A final example is optical computing, which requires getting light in and out of very small waveguides on a semiconductor surface.

It is difficult for human beings to handle very small objects, those less than a millimetre in size, with our hands. In addition, ordinary tools are not made for working with very small objects. Thus, special tools must be developed, and these tools should be approximately the

same size as the small objects that they are handling. Micromachining, a fairly new discipline that developed from the microfabrication techniques used to make integrated circuits, can be used to make such small tools.

In order to avoid clumsy handling by human hands and in order to be able to automate the actions of the little tools, they should have some capability of movement. The terms micromachine and microactuator have been applied in the micromachining field to objects on the micrometer to millimetre scale that have this capability of motion. The movement should preferably be electrically controlled so that the micromachines can be interfaces with integrated circuits, computers, etc. However, in some cases it is desirable that the movement is actuated by some other means. For instance, it may be desired to have chemical control over the movement in a safety valve so that it closes automatically in response to the presence of a toxic gas.

It is also desirable to make microactuators cheaply and with high yield. It has been found that the fabrication methods used for making integrated circuits, called batch fabrication or microfabrication, are also well suited for making mechanical objects.

A structure that has been found to be very useful in large objects is the hinge. Examples of hinges that are used to connect rigid bodies together are all around us: for example, doors are hung to walls on hinges. Examples also exist on the micro-scale: rigid plates made of polysilicon have been hinged on passive, elastic hinges of polyimide (Ref. 1). It is even more useful if the hinges are active, or capable of engendering motion. Your elbows and knees are examples of active hinges: they not only connect the two bones but can be used to position one of them relative to the other. Another example is a clam, which uses a muscle to open and close its shell.

Things that are easy to accomplish when objects are of a size comparable to our own can become quite difficult when the objects are much smaller. One cannot apply the familiar construction techniques, using screws, glue, drills, lathes, etc. In addition, one cannot handle the parts in the usual ways. Thus, in order to make a familiar object on a microscopic scale requires a new approach. A whole new fabrication procedure must be devised that makes use of the technologies appropriate on that length scale.

Broadly speaking, the thickness of microfabricated parts is determined by the thickness of the deposited layers making up that part, and the lateral dimensions are determined by photolithographic masks. Successive deposition and etching steps are used to build structures layer by layer. Final structures are usually attached or pinned to the substrate and are already in proper position with respect to other structures.

Micromachining allows the manufacturing of e.g. sensors and actuators with dimensions of nanometers to centimetres. Specific examples of micromachined objects include motors, pumps, accelerometers, pressure sensors, chemical sensors, valves, micro-motion systems and grippers. Overall surveys of micromachining are found e.g. in Refs 2, 3 and 4. Three broad classes of micromachining are known: surface micromachining, bulk micromachining, and LIGA and its variations.

In surface micromachining, layers are deposited and etched on one side of a wafer (Ref. 5). An example of an organic microactuator built using this technique is given in Ref. 6. This is in contrast with bulk micromachining, in which structures are made directly from a silicon wafer, or wafers of another substrate material, by selectively etching away unwanted parts from the front and/or back sides of the wafer. An example of a microactuator built using this technique is given in Ref. 7. Bulk micromachining has been used for membranes, pumps, and accelerometers. Two or more substrates can also be bonded together and etched. Surface and bulk micromachining methods are compared in Refs 2 and 8. LIGA, and its variations, involves patterning photoresist or some other suitable polymer using x-rays or ultraviolet light and depositing material into the resulting holes in the resist by electroplating (Ref. 9).

A large class of micromachines makes use of a membrane, cantilever beam, or another thin layer to attach a rigid part to the substrate (Ref. 2). The rigid part can be moved either by Method A, applying a force, such as an external pressure or a voltage, to either the flexible thin layer or to the rigid part, or Method B, if the thin layer is made up of two or more components, by changing the volume of one component of the bilayer to make the membrane bend. For a review of actuation mechanisms, see for example Ref. 10. For Method B, piezoelectric materials, such as polyvinylidene fluoride or ZnO, are often

used as actuators, but other materials have also been applied, such as shape memory alloys and thermomagnetic materials (Ref. 11). Examples of structures of Method B fabricated to date include a piezoelectrically actuated micropump (Ref. 12), a piezoelectric cantilever bimorph (Ref. 13), a thermally driven mechanical resonator (Ref. 14), a thermally driven diaphragm valve (Ref. 15), and thermally driven bimorph actuators (Ref. 16).

There are two different prior art methods for forming three-dimensional structures out of the plane of the wafer. The first is of the above Method A, actuators in which the rigid parts are moved by applying a potential between them and electrodes on the substrate. In one implementation, large plates were connected by passive, flexible polyimide hinges and the position of the plates was controlled electrostatically (Ref. 17). In this example, the elastic polyimide layer bent under the applied force. More complex shapes, such as cubes, required manual assembly and could not be moved electrostatically.

In the above Method B for making three-dimensional micromachined structures, polysilicon structural elements were made with integrated staples, and the structures were assembled from these elements by rotating the components out of the plane of the wafer (Ref. 18). This was either done manually, using probes, or during a post-release rinse under the influence of hydraulic forces. Once the structures passed a critical angle with respect to the substrate, a spring-loaded tab on the rotating part snapped into a slot in the structure and was locked into place.

Although these above examples have some similarities with the present invention, the present invention differs essentially from the prior art because according to the present invention hinges are actively used to move and/or position rigid components, such as plates, not just as connectors to the substrate. For example, the structure according to the invention may include plates which may be positioned arbitrarily under electrical control. In preferred embodiments such plates can rotate 180° or more, so that they may be positioned over another part of a substrate (see Fig. 1). Several plates in a row can be rotated 90° (see Fig. 2) so that, in combination with other plates, they can form a cube. In the first prior art method above, the plates are limited to a motion of a few degrees, since the plate must remain over the electrode. In the above Method B, the assembly of the parts occurs at random in the water bath, and the

parts are permanently locked into position thereafter. In the present invention, the extent to which the hinge or hinges is/are bent is controlled by e.g. the applied voltage, so one has precise control over the position of the components and the movement is reversible. Several hinges and components can be connected together to form structures such as self-closing cubic boxes, which have never before been realized.

The other area of prior art that relates to the present invention is microfabricated bilayer actuators with one layer of conducting polymer. Although such actuators have been demonstrated by the inventors of the present application (Ref. 19) and by others (Ref. 20), the application of such actuators as hinges has anyhow not been demonstrated before.

Disadvantages of Non-Micromachined Structures

i. Size

Although there are many macroscopic examples of active hinges that can move rigid structures, both in nature and in technology, these known structures have drawbacks in the manipulation of small objects or in operating within small, confined geometries.

The primary drawback of such existing tools is their large size. Human hands and fingers are examples from nature: it is time-consuming and difficult for us, even with the aid of a microscope and tweezers, to handle objects less than 1 millimetre in size. A technological example is a thermally actuated valve in which the active hinge is a bimetal and the rigid part is an elastomeric poppet (Ref. 21). This device was large, or macroscopic size, and was made using conventional techniques. However, this device is too large to handle, for example, single cells. It could not be made small enough, 100 microns or 10 microns in length, because the parts that made it up could not be fabricated at that size, and even if they could be, they could not be assembled using conventional techniques. Another macroscopic size example is a valve that uses a bilayer to move a pin (Ref. 22). However, this device was not designed for micron-scale manipulations and is too large to do so. A final technological example is macroscopic-size conducting polymer bilayers (Ref. 23), but these again have the drawback of being too large. Therefore, in most cases, micromachining is necessary to make the small tools that are desired.

ii. Control over Motion

There are examples from nature of microscopic hinges moving rigid bodies. However, these have the drawback of not being under our control. An example is the body of an ant, which can handle tiny objects but whose actions we cannot direct. Prior to this invention, there were no equivalent microscopic artificial or man-made tools based on hinges that could rotate essentially rigid components.

iii. Assembly

Although it is possible to construct reasonably small tools from tiny parts, where a Swiss watch would be one example and parts manufactured using LIGA are another, the assembly of such systems has the drawback of being delicate and expensive. In addition, parts that are not firmly attached to anything are easy to loose. The use of micromachining to make small tools avoids these disadvantages because batch fabrication can result in low production costs and because the micromachines are manufactured in such a way that they are already assembled.

Disadvantages of Micromachined Structures with Passive Hinges

Limited Control of Position

There are two classes of hinged devices, those with active hinges and those with passive hinges. Passive bending parts can be flexible and allow a great range of motion. However, although they can be used to connect rigid plates to the substrate and to each other, by definition they cannot themselves be used to move them (Refs 1 and 24). The rigid plate must therefore be moved some other way, such as electrostatically, by applying an electric field between it and another electrode, or magnetically. In the former case, the first drawback is that the two electrodes, of which the plate is one and part of the substrate is usually the other, can never touch. The second drawback is that they must remain over each other, so that the maximum controlled bending is much less than 90°. The plates can be moved further, but only if they are adjusted by hand. The third drawback is that if the passive hinges are stiff instead of flexible, then the range of motion is limited even further. An example with this drawback is a gas valve actuated electrostatically (Ref. 25).

Magnetic actuators allow a large range of motion; they can be bent 180°. They have a part which consists of some magnetic material that can be aligned with an external magnetic field. In one example, the actuator was attached to the substrate by a torsional beam made of polysilicon (Ref. 26). Another, similar type generates the magnetic field directly on the substrate. The drawback of magnetically actuated device is that, because it is the position of the plate that is controlled, rather than the bending of the hinge, it is only possible to control a single plate on a single hinge. It is not possible to make multi-hinged structures which fold up like a box, which would require control over the position of five plates.

The drawback of restricted positions is found with all actuation mechanisms that control the position of the rigid element instead of the bending element.

<u>Disadvantages of Micromachined Structures with Active Hinges</u>

The only presently known active hinge is a bilayer, or bimorph, which consists of at least two layers whose volumes change differently in response to a certain stimulus.

i. Limited Range of Motion

One of the drawbacks of actively hinged microfabricated structures built today is their limited range of motion. Unlike in the passive hinges, the layers that make up the active bending parts of micromachined structures are fairly thick and stiff, so they cannot bend very much. Although the bending parts may connect and move rigid parts, the motion is limited. An examples is a micromachined valve (Ref. 27): the actuation is either piezoelectric or thermal and results in a bend of a membrane. However, this bending is only a few degrees. Another example is a cantilevered beam used as a radiation detector (Ref. 28), which also bent only a few degrees.

ii. Designs Lacking Rigid Components

Many microactuators consist simply of a bimorph without any attached rigid components. Flexible bimorphs have the disadvantage of uncontrolled bending, the inability to do anything but curl, and the inability to transmit the forces generated to another physical location or to apply the forces effectively to another object (Ref. 19). Stiff bimorphs

without rigid components are able to apply force and less likely to suffer from bending in undesired ways, but have the disadvantage of only being able to curl uniformly, without the possibility of more complex or useful action.

iii. Designs Containing Only One Rigid Component

A bilayer with the addition of a single rigid component is a very useful tool; the bilayer positions the rigid element to accomplish some goal, such as the placement of a pin to close a valve or the movement of a mirror. However, they are limited to simple behaviour and have the disadvantage that they cannot undertake more complex actuation tasks.

iv. Limits of Some Actuation Mechanisms

One of the most common ways to actuate a bimorph is with heat; in this case the two layers have different coefficients of thermal expansion, and heating causes the bilayer to bend. An example of this actuation mechanism, on a large scale, is a thermostat. However, there are two drawbacks of using heat to actuate a hinge. The first is that it consumes a great deal of power, and the second is that in environments that dissipate heat, such as in liquids, thermal actuation does not work well.

Another common type of actuation material is shape memory alloys. There are materials that have one shape at one temperature, and a second shape at another temperature. By changing the temperature, the material can be switched between the two states. The drawback of this method is that the material cannot hold a shape intermediate between these two states.

<u>Further Discussion on the Differences Between the Present Invention and Other Micro-Actuators</u>

Although multi-segment thermal actuators have been reported (<u>after</u> the priority date of the present application, Ref. 29), and the segmentation has the advantage of allowing individual control over the bending parts, these devices do not contain rigid components but rather short non-actuated segments. So, although they share the multi-segment feature of the present invention, they are not able to move or

position rigid components, such as plates. They have the additional drawbacks of a small degree of bending and thermal actuation.

A micromachined mirror consisting of a large reflecting plate on a long piezoelectric actuator has also been reported (Ref. 30), after the priority date of the present application, but this actuator did not position the mirror out of the plane of the wafer, but instead applied a torsional or bending vibration to it. Even though the mirror could be bent 30°, this was accomplished at a resonance frequency, so the mirror could not be fixed at that angle but vibrated at approximately 600 Hz. Our invention, on the other hand, is able to not only move a rigid component, such as a plate, to this angle, but to hold it there. The mirror has the second drawback that the bending per unit length of the bending unit is small: the torsional spring bending element is long compared with the size of the mirror. In our invention, the bending elements (the hinges) can be made significantly smaller than the rigid components: we have achieved 180° bending of a plate with area 900 x 900 square microns on a single bending element with an area of only 30 x 30 square microns.

A microactuator that can produce displacements of plates in the plane of the wafer has been demonstrated (Ref. 31) after the priority date of the present application. An important difference is that the present invention results in out-of-plane, or bending, motion.

A common micromachine design, made famous by the Texas Instruments switchable mirrors and now being used in other applications (such as in Ref. 32), is a plate hinged on two sides or two corners that is able to rotate a few degrees around the hinges. Although these can also be described as plates connected to the substrate by hinges, these hinges are passive and the plates are positioned electrostatically. Even if the hinges were active, such a design does not allow the entire plate to be lifted out of the plane of the wafer.

The majority of microactuators make use of inorganic materials for actuation. However, organic materials can undergo much greater volume changes than inorganic materials and can thus offer advantages when used in active hinges. In addition, as passive layers organic materials have the advantage of greater flexibility than inorganic ones.

Objects and Advantages of the Invention

One object of the present invention is to provide a structure capable of handling objects of micrometer (10^{-6} meters, also called

microns) to millimetre size and/or capable of movement within micron sized to millimetre sized spatial volumes without the drawbacks of the prior art methods.

Specifically, an object of the present invention is to provide such a structure which is micromachined so that it has the advantage of appropriate size (the area is determined by the photolithographic patterns used to define the in-plane dimensions of the components). This also gives the structure the advantage of automatic or simple assembly. Further, it has the advantage that it is responsive to some external stimulus, such as a voltage or a chemical signal, so that its motion can be controlled. The structure has active hinges connected to rigid components, giving it the advantage of allowing arbitrary positioning of the rigid components. In addition, the hinges are flexible, so they have a small bending radius and thus the advantage of providing a large range of motion. The essential rigid component(s), referred to as plates in the following as a preferred example thereof, that are moved by the hinge(s) offer one of the most significant advantages. These plates, which can be rotated by hinges whose area is small in comparison, can be used in a variety of ways, some of which are detailed in the embodiments that follow. They can be used as simple reflectors, as rigid elements for the translation of force, as lids to cover holes, as valves or pumps, as temporary barriers or walls, as platforms for electrical devices or other micromachines, etc.

Another very significant advantage is the fact that multiple hinges and plates can be incorporated in a single structure. Complex shapes, such as cubes, can thus be automatically folded together without human manipulation. There is no other actuator in existence that can accomplish this.

In addition, by controlling each segment individually, fine control of a complex structure or set of structures can be achieved. In a multi-hinged structure, only the first plate is bound to the surface, and therefore limited in its motion by the spatial constraint of coming into contact with the substrate. The other plates can be lifted away from the surface and can therefore be positioned e.g. 270° from their original angle, enabling such things as the self-assembling cube.

If actuation materials such as conducting polymers are used, another important advantage is that the bending of the hinges is continuous, that any position between the initial and final positions can

be reached and maintained. Those micro-actuators also have the advantage of being able to work in liquid environments, which is desirable for many biomedical and analytical applications, and the advantage of low power consumption. Conducting polymer actuators also have the advantage of voltage control.

According to a first aspect the present invention provides a micromachined structure or system as defined in claims 1. A micromachined structure or system according to the invention is characterized in that it comprises at least a first essentially rigid component and at least a first flexible bending hinge which is adapted to move and/or position said first component and, to this and, presents in its thickness dimension a first region having a first degree of dimensional change in response to some stimulus/stimuli, and a second region having a different, second degree of dimensional change in response to said stimulus/stimuli. Preferred embodiments of the inventive structure are set out in claims 2-26.

The expression "degree of dimensional change" should also encompass the alternative where the first and second regions of the hinge have the same end-volume change, but with different rates.

If the structure comprises multiple rigid components, as in claim 2, one of these might be in the form of a substrate, as in claim 8.

If the structure comprises multiple hinges, as in claim 2, and a substrate, as in claim 8, some hinges may bend away from the substrate while other hinges may bend towards the substrate.

The moving components might include passive devices for e.g. electrical connection or electromagnetic sensing. Such devices might include contact pads, probes, or needles made of metal, conducting polymer, other conducting material, magnetic-field-inducing material, shape-memory-alloys, or structures coated with such materials.

Especially, such further devices can be used for reflecting electromagnetic energy and comprise especially mirrors for reflecting light.

The moving components can also be so arranged that the whole structure as such can be moved in relation to its environment.

According to one embodiment, the structure is alternately foldable into a compact shape and extendible into an elongated shape.

According to a second aspect the present inventions provides a number of specific uses, as defined in claims 27-33, of a micromachined structure according to the invention.

According to a third aspect, the present invention provides a micromachined device as defined in claim 34, having been assembled by on ore more micromachined structures according to the invention.

According to a fourth aspect, the present invention provides a method for the manufacture of a micromachined device, as defined in claims 35-37.

The above and further features, objects and advantages of the present invention will become apparent hereinafter, with reference to the following examples and the attached drawings.

<u>Elements in Figures</u>

1	substrate
2	hinge
3	rigid plate
4	hinge, bilayer
5	rigid component
6	layer which changes volume
7	layer which does not change volume
8	chromium layer
9	first Au layer
10	BCB layer
11	polypyrrole layer
12	photoresist layer
13	hinges, folding away from substrate
14	hinges, folding toward substrate
15	rigid components, structural elements
16	staples
17	rigid plate, reflecting
18	laser light source
19	light detector
20	laser beam
21	reflected laser beam
22	LED
23	aluminum layer
24	second Au layer

25 conducting polymer for LED
26 ring with hole
27 hole
28 ring with knob
29 knob
30 post
31 cap
32 flexible cap
33 actuator = hinge + rigid plate
34 optical fiber
35 first waveguide
36 second waveguide
37 inlet
38 open outlet
39 closed outlet
40 cavity
41 cell
42 drug release device
43 sensor
44 electrodes
45 micro-gripper

Brief Description of the Drawings

Fig. 1a shows a substrate (1) on which is a microstructure comprising a freed rigid plate (3) on a partially freed hinge (2) with the plate lying flat against the substrate at an angle of 0° with its top side up.

Fig. 1b shows the microstructure of Fig. 1a with the plate (3) having been rotated by the hinge (2) so that it lays flat against the substrate (1) at an angle of 180° with its top side down.

Fig. 2a shows a microstructure comprising five rigid plates (3) connected by hinges (2) to the substrate and to each other. The plates lie flat at angles of 0°.

Fig. 2b shows the microstructure of Fig. 2a with the plates (3) having been rotated 90° by the hinges (2) so that the structure has folded into a box.

Fig. 3 shows a micromachined structure comprising a bilayer (4) and a rigid component (5). The bilayer (4) comprises one layer (6) which can change volume and one layer (7) which does not change volume. Under the application of a stimulus the bilayer (4) bends and lifts the rigid component (5).

Figs. 4a,b through 14a,b are schematic and not to scale: vertical dimensions are greatly exaggerated.

Fig. 4a is a side, cross-sectional view of the first step in the manufacturing of the structure according to Example 1, the deposition of the Cr layer (8) over the Si substrate (1).

Fig. 4b is a top view of the first step in the manufacturing of the structure according to Example 1, the deposition of the Cr layer (8) over the Si substrate (1).

Fig. 5a is a side view of the second step in the manufacturing of the structure according to Example 1, the patterning of the Cr layer (8) over the Si substrate (1).

Fig. 5b is a top view of the second step in the manufacturing of the structure according to Example 1, the patterning of the Cr layer (8) over the Si substrate (1).

Fig. 6.a is a side view of the third step in the manufacturing of the structure according to Example 1, the deposition of a first Au layer (9).

Fig. 6b is a top view of the third step in the manufacturing of the structure according to Example 1, the deposition of the first Au layer (9).

Fig. 7a is a side view of the fourth step in the manufacturing of the structure according to Example 1, the deposition of the benzocyclobutene (BCB) layer (10).

Fig. 7b is a top view of the fourth step in the manufacturing of the structure according to Example 1, the deposition of the BCB layer (10).

Fig. 8a is a side view of the fifth step in the manufacturing of the structure according to Example 1, the patterning of the BCB layer (10).

Fig. 8b is a top view of the fifth step in the manufacturing of the structure according to Example 1, the patterning of the BCB layer (10).

Fig. 9a is a side view of the sixth step in the manufacturing of the structure according to Example 1, the deposition of the polypyrrole (PPy) layer (11).

Fig. 9b is a top view of the sixth step in the manufacturing of the structure according to Example 1, the deposition of the PPy layer (11).

Fig. 10a is a side view of the seventh step in the manufacturing of the structure according to Example 1, the patterning of the PPy layer (11) after the deposition and patterning of a layer of photoresist (12).

Fig. 10b is a top view of the seventh step in the manufacturing of the structure according to Example 1, the patterning of the PPy layer (11) after the deposition and patterning of a layer of photoresist (12).

Fig. 11a is a side view of the eighth step in the manufacturing of the structure according to Example 1, the patterning of the first Au layer (9).

Fig. 11b is a top view of the eighth step in the manufacturing of the structure according to Example 1, the patterning of the first Au layer (9).

Fig. 12a is a side view of the ninth step in the manufacturing of the structure according to Example 1, the removal of the remaining photoresist (12).

Fig. 12b is a top view of the ninth step in the manufacturing of the structure according to Example 1, the removal of the remaining photoresist.

Fig. 13a is a side view of the tenth step in the manufacturing of the structure according to Example 1, the electrochemical oxidation/reduction of PPy to induce the bilayer to bend and release the microstructure from the surface.

Fig. 13b is a top view of the tenth step in the manufacturing of the structure according to Example 1, the electrochemical oxidation/reduction of PPy to induce the bilayer to bend and release the microstructure from the surface.

Fig. 14a shows a side, cross-sectional view of the microstructure folded into a box.

Fig. 14b shows a top view of the microstructure folded into a box.

Fig. 15a-c is a series of photographs of an array of paddles made with the processing sequence of Example 1, rigid plates of surface dimensions 90μm x 90μm on hinges with surface dimensions 30μm x 30μm.

Fig 15a shows the paddles laying flat at 0° with respect to the plane of the substrate.

Fig. 15b shows the paddles rotated 90° with respect to the plane of the substrate.

Fig. 15c shows the paddles rotated 180°.

Fig. 16a-d is a series of photographs of a center-mounted box made with the processing sequence and patterning example used in Example 1. The rigid plates have surface dimensions of 250µm x 300µm and the hinges 50µm x 300µm.

Fig. 16a shows the sides of the box lying flat at 0° with respect to the plane of the substrate.

Fig. 16b shows the sides of the box lifted off the surface by the hinges and starting to fold together.

Fig. 16c shows the sides of the box folded even further together, the grains of sand still visible.

Fig. 16d shows the hinges folded 90° and holding the plates into the shape of a cube or box, the grains of sand completely enclosed.

Fig. 17a is a photograph of a folded side-mounted cube approximately 300µm on each side made with the processing sequence of Example 1.

Fig. 17b is a schematic drawing showing a flat and a partially folded side-mounted cube.

Fig. 18a shows a schematic illustration of an extendor containing hinges that fold both away from (13) and towards (14) the substrate according to Example 2. The two types of hinges use two different types of conducting polymer and are used alternately to connect rigid plates (3). The hinges are open, the plates lay flat against the substrate, and the extendor is fully extended.

Fig. 18b shows the extendor of Fig. 18a with the hinges (13) and (14) folded and the extendor contracted.

Fig. 19a shows a schematic illustration of an extendor containing hinges that fold both away from (13) and towards (14) the substrate according to Example 3. The two types of hinges use the same conducting polymer but a different layer order and are used alternately to connect rigid plates (3). The hinges are open, the plates lay flat against the substrate, and the extendor is fully extended.

Fig. 19b shows the extendor of Fig. 19a with the hinges (13) and (14) folded and the extendor contracted.

Fig. 20a shows a schematic illustration of a hinge (2) being used to assemble rigid structural elements (15) that rotate on staples (16) according to Example 4. The structural elements and staples are both made from inorganic materials used in conventional micromachining,

such as polysilicon. One end of the hinge is attached to the substrate, the other to the top of the structural element.

Fig. 20b shows the same structural element as in Fig. 20a, but with the hinge attached to the bottom of the structural element.

Fig. 21 shows a chemical sensing system according to Example 5 comprising a reflecting plate (17) on a hinge (2), a laser light source (18), and a detector (19). One layer of the hinge changes volume in response to a particular chemical, changing the angle of the plate. A beam of light (20) is directed toward the plate, reflected (21), and the angle of reflection is detected.

Figs. 22a-d illustrate a positionable light emitting diode (LED) according to Example 6.

Fig. 22a shows the basic elements: a hinge (2), a rigid supporting plate (3), gold (9) and (23) aluminum contacts to the LED, and the light emitting area of the LED (22).

Fig. 22b is the cross sectional view indicated by A-A' on Fig. 22a showing the substrate (1), a patterned chromium layer (8), a first gold layer (9), a rigid benzocyclobutene layer (10), and an aluminum contact layer (23).

Fig. 22c is the cross sectional view indicated by B-B' on Fig. 22a showing the substrate (1), a patterned chromium layer (8), a gold layer (8), a rigid benzocyclobutene layer (10), the polypyrrole used for bending the hinge (11), and second gold contact layer (24), a second conducting polymer layer (25) used in the LED, and an aluminum contact layer (23). The layers (23), (24), and (25) make up the simple LED (22).

Fig. 22d shows the LED shining parallel to the substrate surface.

Fig. 22e shows the LED shining through a hole in the substrate surface.

Fig. 23a-e illustrates a possible way to use bilayer (or multilayer) hinges to assemble components in accordance with Example 7.

Fig. 23a shows the elements of such a system before assembly, which include a bilayer hinge (4) connected to some rings (26) with holes (27), other rings (28) with knobs (29), one of which is around post (30) with a cap (31). A top view is shown on the left, a cross-sectional view is on the right.

Fig. 23b shows a top view such a system after assembly.

Fig. 23c is cross section A-A' of Fig. 23b.

Fig. 23d is cross section B-B' of Fig. 23b.

Fig. 23e is a close-up of the circled area in Fig. 23c showing a ring (26) with a hole on a ring (28) with a knob. The knob has a small cap (32) which allows the ring (26) to slide on but not off.

Fig. 24a,b illustrates the use of an actuator made from a hinge and a rigid plate to position an optical fiber according to Example 9.

Fig. 24a shows the actuator (33) flat against the substrate surface and the fiber (34) guiding light into a first waveguide (35).

Fig. 24b shows the actuator (33) pushing the fiber (34) so that it guides light into a second waveguide (36).

Fig. 25 a-f illustrates the use of hinges to rotate large flaps covering almost the entire substrate surface in accordance with Example 10.

Fig. 25a is a top view of such a system with the flaps lying flat against the surface.

Fig. 25b is a top view of such a system with the flaps partially raised, at an angle of approximately 45° with respect to the substrate.

Fig. 25c is a top view of such a system with the flaps rotated so that their bottom sides are facing up, at an angle of 180° with respect to the substrate.

Fig. 25d is a side view of such a system with the flaps lying flat against the surface.

Fig. 25e is a side view of such a system with the flaps partially raised, at an angle of approximately 45° with respect to the substrate.

Fig. 25f is a side view of such a system with the flaps rotated so that their bottom sides are facing up, at an angle of 180° with respect to the substrate.

Fig. 26 is a sketch of a microstructure with crawling movement according to Example 11.

Fig. 27 illustrates the use of a rigid plate on a bilayer hinge being used as a stop valve in accordance with Example 12. The fluid flows into the valve system through inlet (37) and exits through the open outlets (38) but not the closed outlets (39). In this figure, the fluid exits through two outlets.

Fig. 28a-c illustrates the use of plates on hinges as movable walls that can be used to direct e.g. particle flow according to Example 13.

Fig. 28a shows the such a system with all the flaps down, parallel to the substrate. The particles enter at the inlet (1) and exit at the outlet (2).

Fig. 28b shows how selected flaps could be raised 90° to direct the particles over a single selected area, the one in the upper left hand corner, before exiting.

Fig. 28c shows a different configuration that could be chosen which directs the particles over two areas before exiting.

Fig. 29 shows a cell analysis system in accordance with Example 14. A bilayer hinge (4) is used to rotate a flap (5) so that it seals off a cavity (40) etched in the substrate (1), acting as a lid. A single cell (41) is trapped in the cavity and is dosed with a chemical released from drug release device (42). Sensor (43) detects the response of the cell. Electrodes (44) are used to control and/or measure these steps.

Fig. 30 shows rigid plates on bilayer hinges placed in a channel so that they can be used for pumping e.g. fluid in accordance with Example 15.

Fig. 31 illustrates a bilayer hinge (4) lifting a rigid plate (3) on top of which has been built a micro-gripper (45), according to Example 16. In this figure, the gripper is actuated by a so-called comb drive.

Fig. 32a,b shows a microstructure with snake-like wriggling movement in accordance with Example 17.

Fig. 32a shows the microstructure, comprising hinges that bend upward (13), hinges that bend downward (14), and a rigid "head" (5), lying flat. The two types of hinges are connected directly together in serial.

Fig. 32b shows the microstructure with the hinges bent.

Fig. 33a,b shows part of a microstructure with bending or spiralling movement in accordance with Example 17.

Fig. 33a shows the positioning part of the microstructure, comprising hinges that bend upward (13) and hinges that bend downward (14), lying flat. The two types of hinges are connected directly together in parallel.

Fig. 33b shows the two hinges bending, giving a twist.

Examples for Carrying out the Invention

The following examples are intended to illustrate but not to limit the scope of the invention.

The present micromachined structures are briefly described below with reference to the enclosed Fig. 3. A preferred embodiment is further described in the below Example 1.

The micromachined structure comprises one or more sets of hinges and mechanically rigid components with:

a) The hinge(s) being essentially bilayers or multilayers (4), comprising one or more layers which can change volume (6) and possible zero, one, or more layers which do not change volume (7). This also includes the case of a layer of a single material which behaves as a bilayer or multilayer in that the volume change is not uniform across its thickness in either space or time. The volume change causes the hinges to bend and occurs because of the application of some stimulus/stimuli, said stimulus/stimuli being for example a) electromagnetic or electrochemical, such as a voltage, current, current pulse, or magnetic field, b) thermal, such as a temperature, temperature change or gradient, or a heat pulse, c) optical, such as a laser beam or light level, d) chemical, such as a concentration or dose of one or more chemicals or biochemicals or a change in their level, such as a change in pH, e) mechanical, such as pressure, and/or f) nuclear, such as a radiation dose, but not limited thereto.

b) The essentially rigid components (5) being non-bending. They can be simple plates or more complicated systems of sensors, actuators, or circuitry whose position in space is controlled by the action of the hinge(s). The rigid components may themselves contain smaller moving parts, such as a microgripper: the position of the microgripper being controlled by the bilayer hinge(s), and the gripping action by elements on the rigid plate.

<u>Example 1</u>

Hinged actuators were manufactured in accordance with the below description with reference to Figs. 4a,b -14a,b.

Standard 3-inch diameter silicon (Si) CZ wafers (from Okmetic, Espoo, Finland) 380 micrometers thick, (100) orientation, p-type, boron-doped, 1-20 Ohm-cm conductivity, were used as substrates.

On the polished side of the wafers, a 30Å-thick adhesive layer of chromium (Cr) was deposited by vacuum evaporation (Fig 4a,b). The Cr layer was then patterned by wet chemical etching to leave a rectangular opening in the Cr inside which the Si was exposed (Fig 5a,b). The base of one of the actuator hinges would later be fixed to the edge of the rectangle, and the rest of the actuator would lift off the bare Si areas. The patterning was done by spin-coating the Cr layer with photo resist (Microposit 1818S Photo Resist, Shipley Europe Ltd., Coventry, England) at 8000 r.p.m. for 30 seconds (on a Headway Research Inc., Garland, Texas spinner) followed by soft baking at 100°C for 90 seconds on a hot plate. The resist was exposed to UV light through a Cr/glass mask (mask blanks from Ulcoat, Tokyo, Japan) using a mask aligner (Karl Süss KG, type 401000, München, Germany) for 6 seconds at an intensity of approximately 5 mW/cm2 measured at a wavelength of 365 nm. The resist was developed for 60 seconds in Microposit 351 Developer diluted 5:1 in water. The Cr was then etched in a standard Cr-etch solution of 3.5 g $Ce(SO_4)_2 \cdot 4H_2O$, 17.5 ml HNO_3 (65%), and 32.5 ml H_2O. All chemicals were purchased from E. Merck, Darmstadt, Germany. After the Cr was etched, the resist was stripped with remover (Microposit Remover 1112 A) diluted with an equal amount of water. Developing, etching, and stripping were done at room temperature.

Over the patterned Cr layer, a 200Å-thick layer of gold (Au) was deposited by vacuum evaporation (Fig 6a,b). The gold layer formed the first layer of the bilayer hinge. It also served to connect the rigid layer with the second layer of the hinge, described below. Immediately prior to the evaporation, the Cr layer was etched briefly in Cr-etchant (described above), rinsed in a dilute nitric acid solution, rinsed in water, and blown dry with a stream of nitrogen to remove any native oxide.

Benzocyclobutene (BCB, from Dow Chemical Corporation, 46% in mesitylene) was applied and patterned, forming the rigid plates (Fig. 7a,b and Fig. 8a,b). BCB was spin coated at 4000 r.p.m. for 90 seconds followed by baking in an oven in air atmosphere. The wafers were put into the oven at 100°C and the temperature was ramped up to approximately 200°C over 25-30 minutes, the wafers were held at approximately 200° for 10-15 minutes, the temperature was ramped back down to approximately 120° over approximately 30 minutes, and the wafers were removed. Photoresist was applied to the BCB and patterned as described above. The BCB was etched using reactive ion

etching (RIE) in a plasma with 80 ccm oxygen and 10 ccm CF4 at an RF power of 350 mW. The plasma etched both the resist and the BCB. The etching was halted when the BCB had been completely removed from those areas where it was unwanted, and the gold was exposed in those areas, after approximately 30 minutes. The thickness of the remaining BCB was approximately 10,000Å, patterned into various shapes, e.g. 300 μm x 300 μm squares.

Polypyrrole (PPy), a conducting polymer, formed the second layer of the bilayer hinge. It was polymerized electrochemically onto the exposed gold surface to a thickness of 3000-5000Å at a constant 0.6 V in a solution of 0.1 M pyrrole monomers (purchased from E. Merck and distilled prior to use) and 0.1 M of the sodium salt of dodecylbenzenesulfonate (Na.DBS) (from Aldrich, Steinheim, Germany) in deionized water (Fig. 9a,b).

Resist was spin coated over the PPy, soft-baked, exposed, and developed as described above. The PPy was then etched by dry chemical etching using RIE in an oxygen plasma (Fig. 10a,b). The PPy was left between the rigid BCB plates and over parts of the Au covered Cr areas.

The exposed Au was etched away (Fig. 11a,b) using a standard gold-etch solution of 1g I2, 2g KI, and 50 ml H2O (chemicals purchased from E. Merck). The overlying resist/ PPy layers protected the Au underneath from chemical attack; after this etching, Au was left only under the PPy. The photoresist remaining over the PPy was removed by RIE in an oxygen plasma: the plasma was turned off when the PPy was exposed (Fig. 12a,b).

Electrochemical oxidation/reduction of the PPy layer in an electrolyte, such as 0.1 M Na.DBS (E. Merck) in deionized water, resulted in a change in its volume. The bimetal hinges, consisting of gold and PPy, therefore bent, and the bilayers lifted themselves and the rigid plates from the surface (Fig 13a,b). When the hinges bent 90°C, the microstructure folded into a cube (Fig. 14 a,b).

Figs. 15 -17 show some of the devices made with the above processing sequence. Fig. 15a-c is a series of photographs of an array of paddles: the rigid plates have surface dimensions of 90 μm x 90 μm and the hinges 30 μm x 30 μm. In Fig. 15a, the paddles lie flat with the PPy and BCB facing up, in Fig. 15b they are rotated at approximately 90°, and in Fig. 15c they have rotated 180° and are again lying flat, but with the gold back-side facing up. Figs.16 a-d is a series of photographs of a

center-mounted box closing as the applied voltage is changed. There are two small grains of sand in the box. Fig. 17a shows a photograph and Fig. 17b shows a schematic drawing of a side-mounted box manufactured in accordance with Example 1.

Example 2

Extending/contracting elements can be manufactured in accordance with the below description with reference to Fig. 18a,b.

Using two different types of bilayers, one that bends upwards and one that bends downwards, one could make an extendor. This could be done by using a) two different conducting polymers or b) one conducting polymer doped with two different anions, e.g. one with mobile cations and one with mobile anions, so that one that expands and the other contracts under an applied voltage. By alternating the type of conducting polymer on successive hinges, the plates could be made to fold, allowing enormous elongations and contractions. Such hinged actuators with both upward and downward bending could be made with a processing sequence essentially in accordance with Example 1. The only significant change required in relation to Example 1 would be to deposit and pattern two conducting polymer layers rather than one.

Example 3

One can make an extendor with the same action as in Example 2 but by using only one type of conducting polymer and changing the bilayer orientation for successive hinges - see Fig. 19a,b. For a hinge with the gold below the polymer, the contraction of the bilayer would cause a folding upward from the substrate. If the gold is above the polymer, a folding downward toward the substrate will result.

Example 4

A bilayer hinge can be used to assemble polysilicon or other inorganic structural elements into a three-dimensional structure in a controlled manner - see Fig. 20a,b. Prior art Method b) above made use of the hydraulic forces in a water rinse to assemble such structures. By using bilayer hinges, each component of a complex structure can be positioned accurately and in the required sequence, allowing more complicated designs and giving greater yield. If desired, after assembly

the bilayers can be removed by etching to leave only the final polysilicon structure.

Example 5

Using the processing sequence of Example 1, one can construct a chemical sensor by replacing the PPy/DBS layer with another layer which changes volume as the result of the presence of the chemical to be detected - see Fig. 21. The concentration of the substance is determined by the position of the flap, for example by detecting the reflection of a beam of laser light. The rigid face of the paddle is reflecting because the BCB is transparent, showing the gold underneath it. One could also add an additional reflecting layer over the BCB if desired. With simple modifications the above mentioned sensor can also be used as, or part of, a display unit.

Example 6

Using a processing sequence similar to that of Example 1, one can make a micron sized, positionable light emitting diode (LED) - see Fig. 22a-e. For example, a simple polymer LED can be made from gold layer, a layer of the conducting polymer poly(3-(4-octylphenyl)2,2-bithiophene), and a layer of aluminum. Placing these three layers over the BCB layer would allow the LED to be moved. To make electrical connections to the LED, two thin strips of BCB could be placed on the flexible hinge without interfering with its bending, and the gold lead taken from the device to a contact over one insulating BCB strip and the aluminum over the other. The LED could thus be made to shine e.g. parallel to the silicon wafer or into a hole etched in the wafer.

Example 7

The bilayers can be used to assemble parts made by the LIGA process. The LIGA process, and related electroplating techniques, can produce metal structures loose from the substrate. Devices made from these parts must now be assembled by hand. By using bilayer hinges, each component of a complex structure can be positioned accurately and in the required sequence, allowing more complicated designs, giving greater yield, and without loss of or damage to the parts. If desired, after

assembly the bilayers could be removed by etching to leave only the final structure.

For a simple example of how this might work, refer to Figs. 23a-e. A set of rings is produced by LIGA and/or another surface micromachining technique. One of the rings is fixed to the substrate by a post and cap. Some rings have knobs, comprising smaller posts and caps on either end, the posts being made of the same material as the ring and the caps of a material which is somewhat flexible and shaped like a barb. The other rings have holes on either end large enough to fit around the knobs of the first rings and to slide over the barbs when being put over the posts. Once on, the second set of rings cannot be removed because they cannot slide over the barbs in the other direction. The second set of rings can be snapped onto the first set by the bending of bilayers attached to them. If the bilayers are removed after assembly, then the result is a chain with one loose end and one end fixed to the substrate. If the small posts on the first set of rings do not have barbed caps, then the chain could be disassembled again.

<u>Example 8</u>

Hinge/rigid element actuators could be used to position objects external to the wafer, such as optical fibers, relative to components on the wafer, such as waveguides. By using bilayer hinges, the parts can be positioned accurately and fixed into position by employing e.g. a glue or a mechanical clamp, or the bilayer hinges can be used to actively position the parts relative to each other using e.g. a feedback system. In the first case, the bilayers could be removed after assembly to leave only the final structure. In the second case, the bilayers would control the position of the part during use of the device and/or during calibration or self-testing.

<u>Example 9</u>

Hinge/rigid actuators could be used to switch the position of objects external to the wafer, such as optical fibers, relative to components on the wafer, such as a waveguide. Refer to Fig. 24a,b. By using, for instance, a paddle on a bilayer hinge, the fiber can be made to change position, for example guiding the light into two different waveguides according to some stimulus, such as the presence of a gas in the environment or a change in applied voltage.

Example 10

With the processing sequence of Example 1, minute hinges were able to move large areas: hinges 30 μm x 30 μm in area were able to lift rigid plates as large as 900 μm x 900 μm. Because only a minute hinge is needed to move large areas, one could cover a substrate surface with rigid flaps rotating on thin hinges. Refer to Figs. 25a - d. The surface area devoted to the hinges would be small. By using rigid plates with different properties on their top and under-sides, activating the hinges to rotate the plates 180° would transform virtually the entire surface. The surface properties that can be changed include, but are not limited to, reflectivity, chemical reactivity, and morphology.

If the plates were not rotated 180°, but only part way, then a surface with a different topology would be created. Thus, for example, fluid flow patterns over the surface would be altered.

Example 11

Microrobots that can walk, swim, or climb would be advantageous in e.g. minimally invasive surgery. According to the present invention microrobots can be made with limbs manufactured from rigid plates in combination with active hinges -see Fig. 26.

Example 12

A simple rigid plate on a bilayer hinge can be used as a stop valve - see Fig. 27. By raising (90° relative to the substrate) and lowering (flat against the substrate) a flap placed in front of a channel, one can open or close the valve. One can build a system of many valves and channels to direct the flow of fluid, particles, bacteria, etc.

Example 13

By raising (90° relative to the substrate) and lowering (flat against the substrate) selected flaps placed over the surface of a wafer, one can create a particular pattern, or maze that directs the flow of e.g. particles, cells, or bacteria - see Fig. 28a-c. The pattern of raised gates can be changed to redirect the flow. Thus, because there can be a very large number of different patterns, the particles can be sorted into a large number of groups or be made to undergo numerous different reactions on different parts of the substrate.

Example 14

Because they can swing around to cover areas in another location, flaps rotated by bilayer hinges could be used as lids for depressions in the substrate - see Fig. 29. Such a "clam" geometry would produce an enclosed cavity that could be sealed against the surrounding environment and later reopened. Because the pit and the paddle would be spatially separated during fabrication, they could be tailored and optimized independently. Various things could be put into the pit and studies of small objects, for instance single cells, could be done. Electrodes, for example, could be put on opposite sides of it, or one electrode could be put into the hole and another on the lid. Another conducting polymer could line the pit and be used either for sensing or to release a dose of a certain chemical into the sealed cavity, provoking the cell. Polymer light emitting diodes could be placed in the bottom, and photo detectors on the surface of the flap to enable optical analysis. If silicon was used as the substrate, integrated signal amplification and processing could be placed adjacent to each cavity. The above-mentioned lids may be provided with needle- or knife-like projections.

Example 15

Actuators similar to those of Example 12 can be placed in a channel and used as pumps - see Fig. 30.

Example 16

A microgripper or other small micromachine, such as a microcutter, can be fabricated over the rigid plate - see Fig. 31. The bilayer hinge positions the gripper in space, and the gripper independently opens and shuts to grab small objects.

The positioning of the one or more micro-grippers, or other small micromachine, may be achieved by the one or more hinges and in the gripping or cutting may be independently achieved by the rigid components or by further devices attached to the rigid components.

Example 17

Actuators comprising bilayer hinges connected directly to each other, possibly without any intervening rigid layers, can be

manufactured in accordance with the below description with reference to Figs. 32 and 33.

By connecting hinges that bend upwards with hinges that bend downwards is made an actuator with snake- or worm-like movement, possibly with a rigid "head" or "end". Serial connections can be made as described in the above Examples 2 and 3 without the rigid layers between the hinges. Parallel connections will allow twisting movements to be achieved. Devices in which are combined parallel and serial connections allow for arbitrary movement and positioning of the "head" and/or "end".

The present invention also comprises other embodiments in which the rigid part(s) comprise(s) one or more further device(s), such as light emitting diodes, sensors, actuators, other microfabricated structures, and/or electrical circuitry.

Included in the present inventions are also embodiments in which the volume changing layer(s) in at least one of the bi- or multilayer hinges can both expand and contract.

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CLAIMS

1. A micromachined structure or system, characterized in that it comprises at least a first essentially rigid component and at least a first flexible bending hinge, which is adapted to move and/or position said first component and, to this and, presents in its thickness dimension a first region having a first degree of dimensional change in response to some stimulus/stimuli, and a second region having a different, second degree of dimensional change in response to said stimulus/stimuli.

2. A micromachined structure as claimed in claim 1, further comprising one or more second essentially rigid components and one or more second flexible bending hinges, which are adapted to move and/or position said second components and each of which presents, in its thickness dimension, a first region having a first degree of dimensional change in response to some stimuli, and a second region having a different, second degree of dimensional change in response to said stimuli.

3. A micromachined structure as claimed in claim 2, wherein the operation of said first and second hinges can be controlled individually.

4. A micromachined structure as claimed in any one of claims 1-3, wherein said first degree of dimensional change and said second degree of dimensional change are both non-zero.

5. A micromachined structure as claimed in any one of claims 1-3, wherein said first degree of dimensional change is non-zero and said second degree of dimensional change is zero.

6. A micromachined structure as claimed in any one of the preceding claims, wherein said first hinge/at least one of said first and second hinges comprise(s) at least two layers defining said first and second regions.

7. A micromachined structure as claimed in any one of the preceding claims, wherein said first hinge/at least one of said first and second hinges comprise(s) at least one layer having a degree of

dimensional change that varies across its thickness dimension, thereby defining said first and second regions.

8. A micromachined structure as claimed in claim 1, comprising a substrate to which said first component is connected by said first hinge.

9. A micromachined structure as claimed in claim 8, wherein said first component can be moved and/or positioned by said first hinge in relation to the substrate to such an extent that said substrate and said first component together form a microgripper.

10. A micromachined structure as claimed in claim 8, further comprising one or more second essentially rigid components connected to said substrate by one or more second flexible bending hinges, each of which presents, in its thickness dimension, a first region having a first degree of dimensional change in response to some stimuli, and a second region having a different, second degree of dimensional change in response to said stimuli.

11. A micromachined structure as claimed in claim 8, further comprising one or more second essentially rigid components, which are directly or indirectly connected to said first component by one or more second flexible bending hinges each of which presents, in its thickness dimension, a first region having a first degree of dimensional change in response to some stimuli, and a second region having a different, second degree of dimensional change in response to said stimuli.

12. A micromachined structure as claimed in claim 11, wherein said first and second components can be moved and/or positioned by said first and second hinges in relation to each other to such an extent that said first and second components together form a microgripper.

13. A micromachined structure as claimed in any one of the preceding claims, wherein said first hinge/at least one of said first and second hinges present(s) a maximum bending angle of at least 180°.

14. A micromachined structure as claimed in any one of the preceding claims, wherein said stimulus/stimuli is/are at least one of the following:

a) electromagnetic or electrochemical, such as a voltage, current, current pulse, or magnetic field;
b) thermal, such as a temperature, temperature change or gradient, or a heat pulse;
c) optical, such as a laser beam or light level;
d) chemical, such as a concentration or dose of one or more chemicals or biochemicals or a change in their level, such as a change in pH;
e) mechanical, such as pressure; and/or
f) nuclear, such as a radiation dose.

15. A micromachined structure as claimed in any one of the preceding claims, wherein at least one dimension of the rigid component(s) is larger than the radius of curvature of the hinge(s).

16. A micromachined structure as claimed in claim 15, wherein said first component/at least one of said first and second components is/are in the form of a plate being attached to a flexible bending hinge the area of which is smaller than the area of the plate.

17. A micromachined structure as claimed in any one of the preceding claims, wherein said first hinge/at least one of said first and second hinges comprise(s) at least one organic layer the volume of which is changeable

18. A micromachined structure as claimed in any of the preceding claims, wherein said first hinge/at least one of said first and second hinges comprises a conjugated polymer layer, such as a polypyrrole layer.

19. A micromachined structure as claimed in claim 18, wherein the hinge which comprises a conjugated polymer layer further comprises a solid electrolyte layer, such as a polymer electrolyte layer or a hydrogel layer.

20. A micromachined structure as claimed in claim 18, wherein the hinge which comprises a conjugated polymer layer is capable of operation in a liquid electrolyte, such as blood, salt water, etc.

21. A micromachined structure as claimed in any one of the preceding claims, wherein said first component/at least one of said first and second components, , comprise(s) or support(s) one or more active devices, such as light emitting diodes, sensors, actuators, other microfabricated structures, and/or electrical circuitry.

22. A micromachined structure as claimed in any one of the preceding claims, wherein said first component/at least one of said first and second components forms an openable and closable lid, such as a lid for an opening, hole, pit or indentation in a substrate.

23. A micromachined structure as claimed in any one of claims 2-22, wherein said first and second hinges comprises at least two hinges which are connected directly to each other.

24. A micromachined structure as claimed in claim 23, wherein said two hinges are serially connected to each other.

25. A micromachined structure as claimed in claim 23, wherein said two hinges are connected in parallel to each other.

26. A micromachined structure as claimed in any one of the preceding claims, wherein said first and second degrees of dimensional change of said first hinge / of at least one of said first and second hinges are such that the hinge can both expand and contract in response to said stimulus/stimuli and thereby bend in two directions.

27. Use of a micromachined structure as claimed in any one of Claims 1 - 26 for detecting and/or indicating one or more states of a surrounding environment of the structure, by moving and/or positioning said rigid component(s) by said hinge(s).

28. Use of a micromachined structure as claimed in any one of Claims 1 - 26 as a display element.

29. Use of a micromachined structure as claimed in any one of Claims 1 - 26 for particle or cell sorting or routing, the erection of barriers, or gas or fluid flow control or pumping, by moving and/or positioning said rigid component(s) by said hinge(s).

30. Use of a micromachined structure as claimed in any one of Claims 1 - 26 for changing a surface property, such as the topography, the reflectivity or the chemical properties of a substrate surface, by moving and/or positioning said rigid component(s) by said hinge(s).

31. Use of a micromachined structure as claimed in any one of Claims 1 - 26 for establishing an electrical or other sensory contact by moving and/or positioning said rigid component(s) by said hinge(s).

32. Use of a micromachined structure as claimed in any one of Claims 1 - 26 for moving and/or positioning a source of electromagnetic radiation and/or detector of electromagnetic radiation, by moving and/or positioning said rigid component(s) by said hinge(s).

33. Use of a micromachined structure as claimed in any one of Claims 1 - 26 for analyzing or exerting effects on one or more small objects, such as biological cells, by moving and/or positioning said rigid component(s) by said hinge(s).

34. A micromachined device, characterized in that it comprises parts which have been assembled by the aid of one or more micromachined structures as claimed in any one of Claims 1 - 26.

35. A method for the manufacture of a micromachined device from a number of parts, characterised by the step of assembling at least some of said parts by the aid of at least one micromachined structure as claimed in any one of claims 1-26.

36. A method for the manufacture of a micromachined device as claimed in claim 35, wherein said micromachined structure is also used, at least partially, as a structural part of the final micromachined device.

37. A method for the manufacture of a micromachined device as claimed in claim 36, comprising the step of removing at least one hinge from the micromachined structure, subsequent to the assembly of said parts of the micromachined device, whereby a remaining portion of the micromachined structure forms a structural part of the final micromachined device.

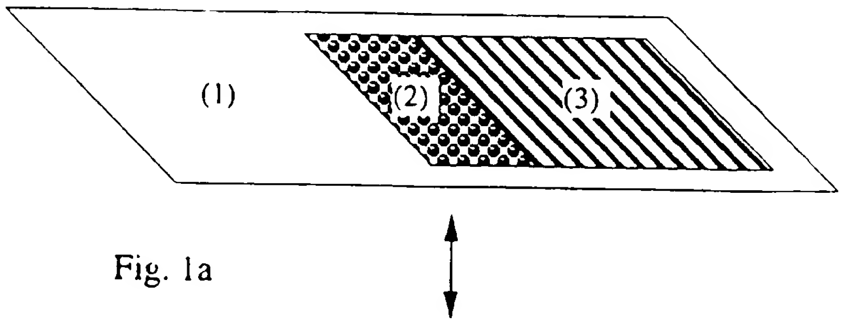


Fig. 1a

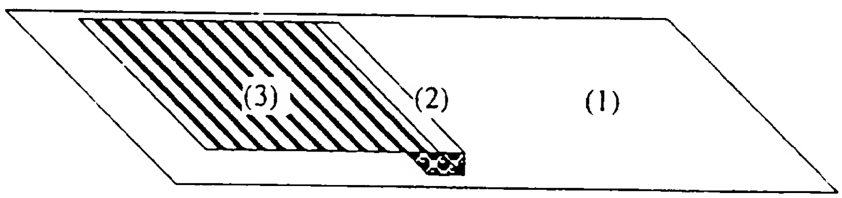


Fig. 1b

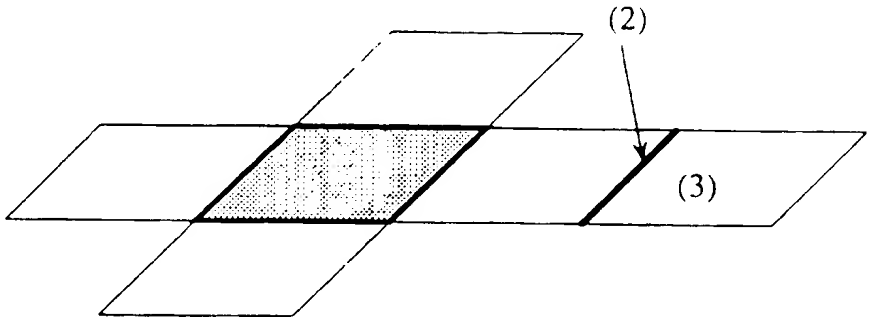


Fig. 2a

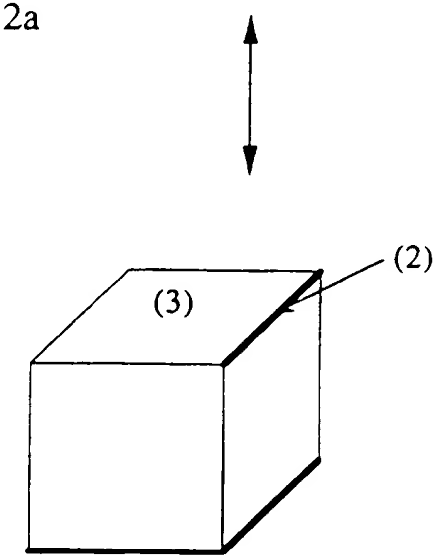


Fig. 2b

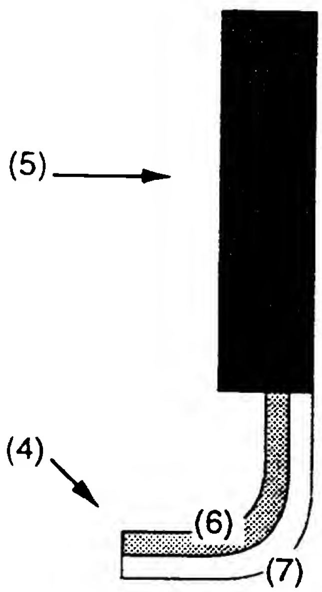


Fig. 3

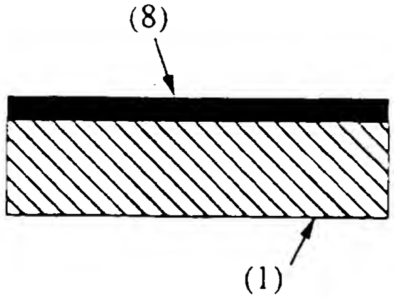


Fig 4a

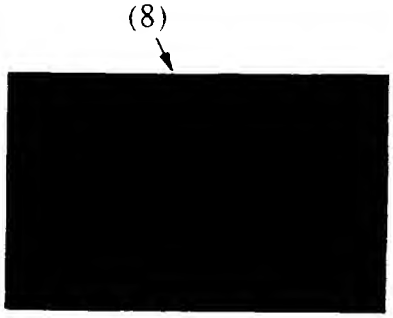


Fig 4b

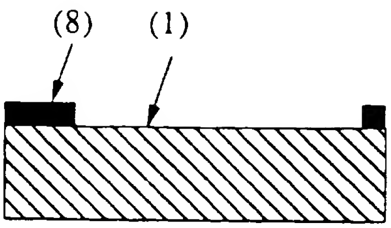


Fig 5a

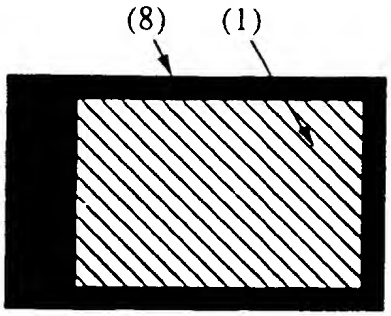


Fig 5b

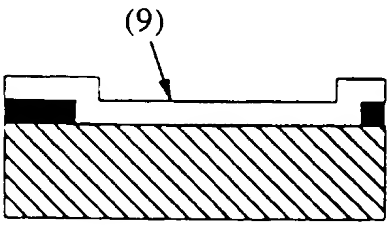


Fig 6a

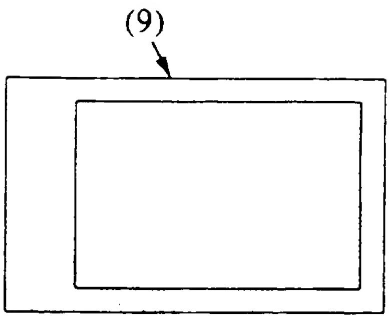


Fig 6b

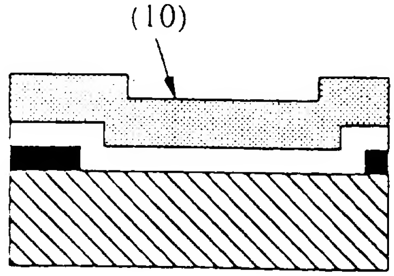


Fig 7a

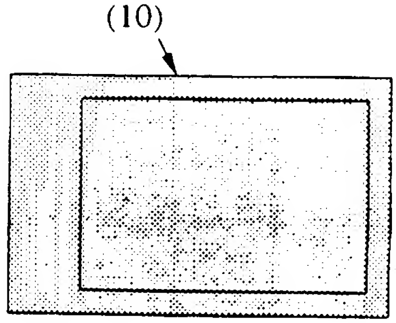


Fig 7b

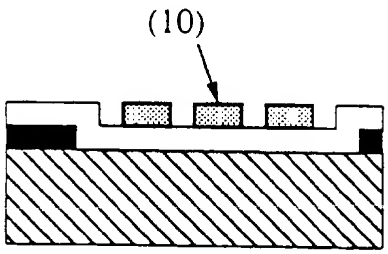


Fig 8a

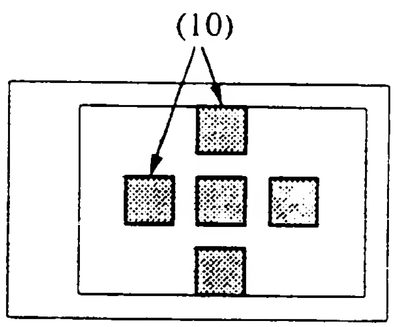


Fig 8b

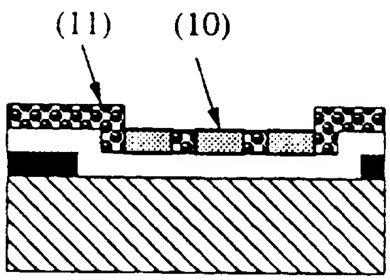


Fig 9a

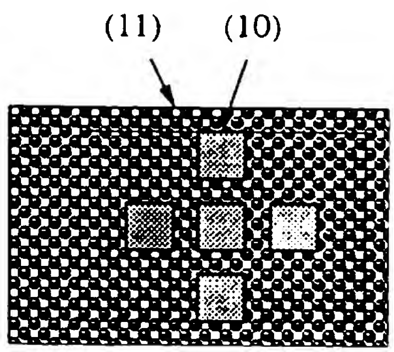


Fig 9b

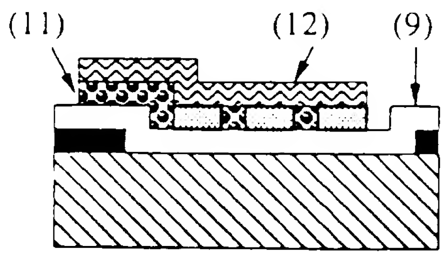


Fig 10a

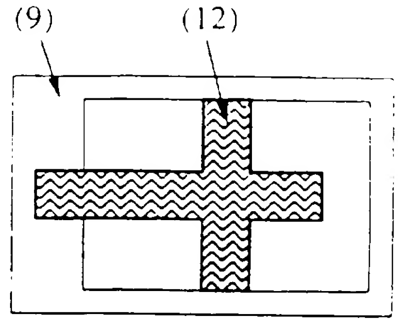


Fig 10b

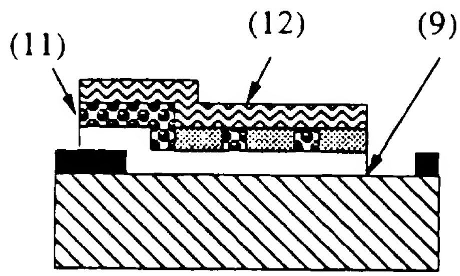


Fig 11a

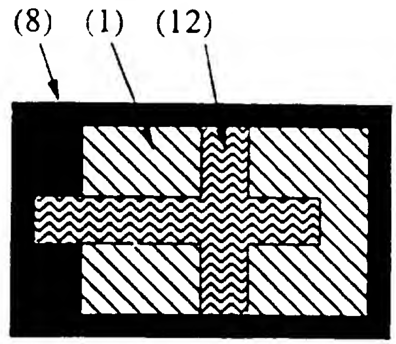


Fig 11b

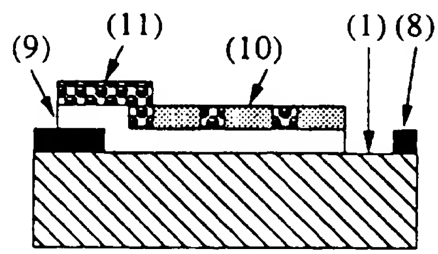


Fig 12a

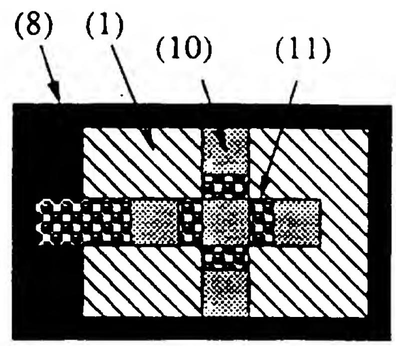


Fig 12b

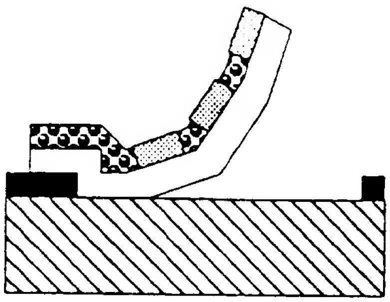


Fig 13a

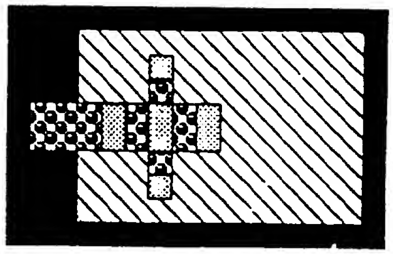


Fig 13b

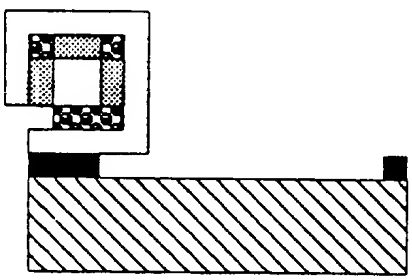


Fig 14a

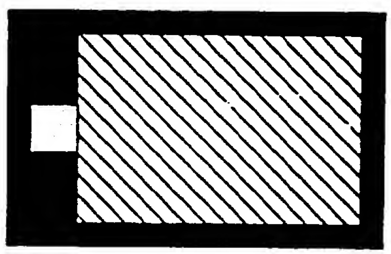


Fig 14b

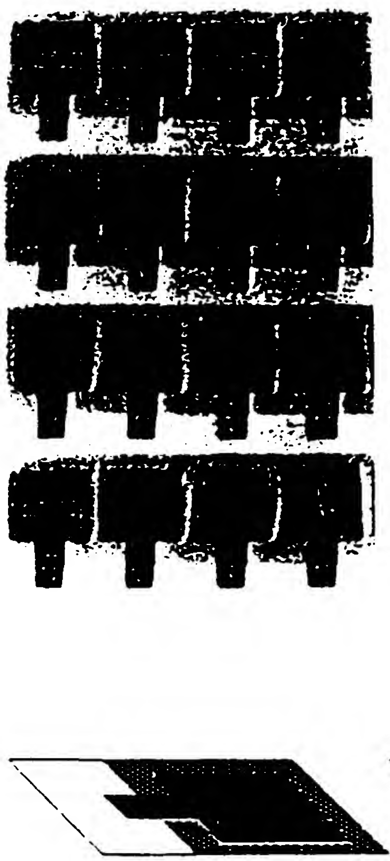


Fig. 15a

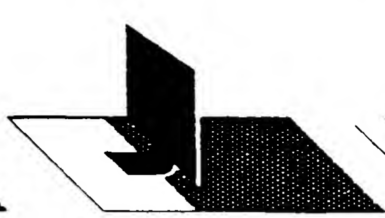


Fig. 15b

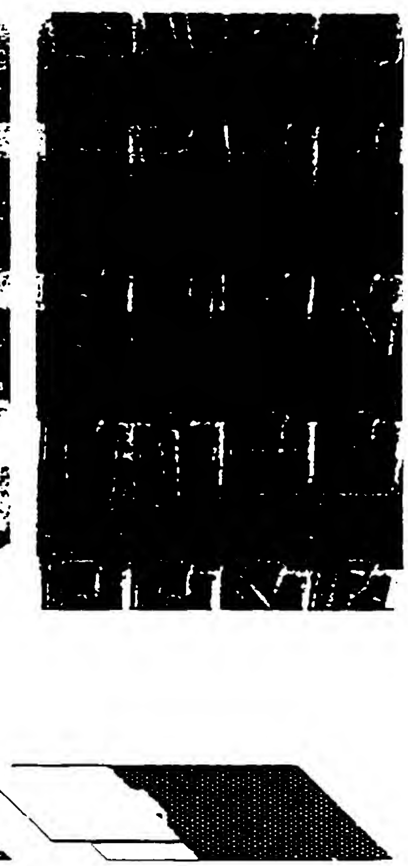


Fig 15c

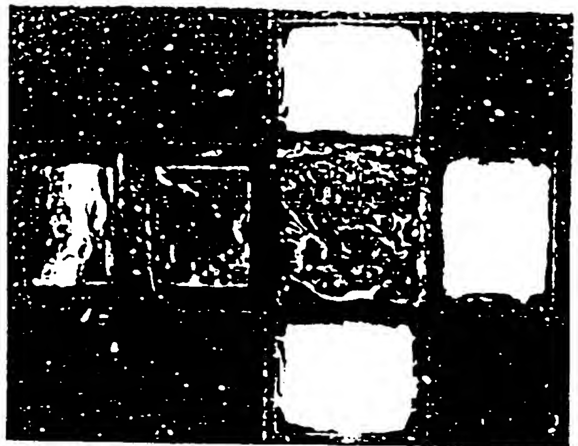


Fig 16a

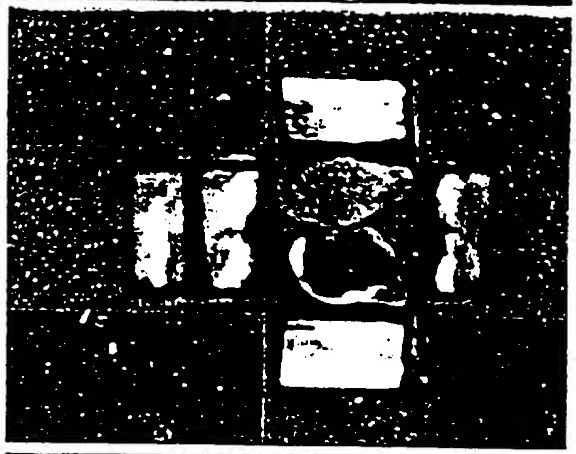


Fig 16b

Fig 16c

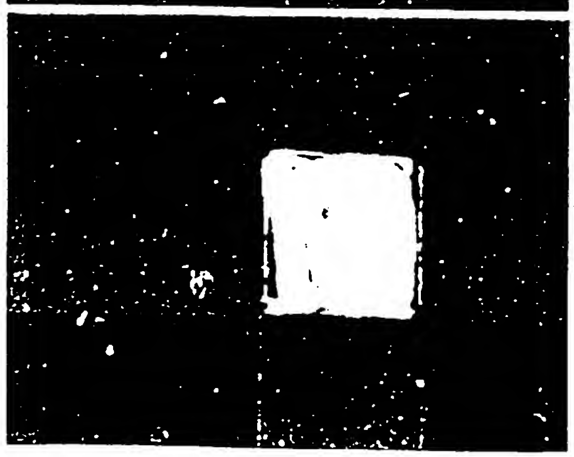


Fig 16d

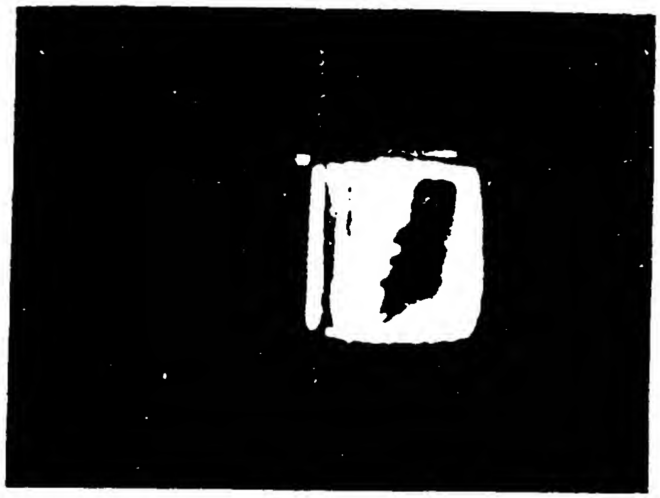


Fig 17a

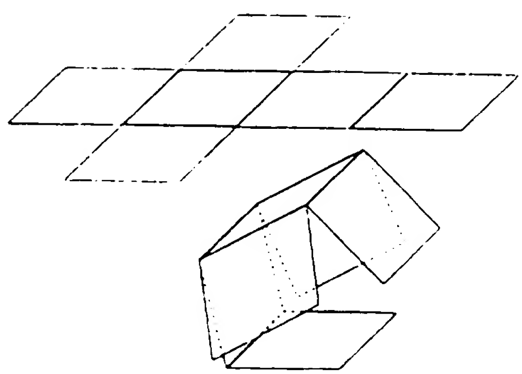


Fig 17b

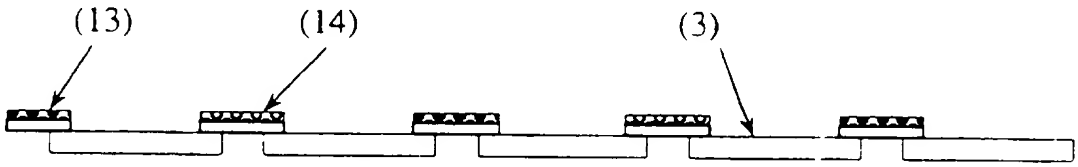


Figure 18a

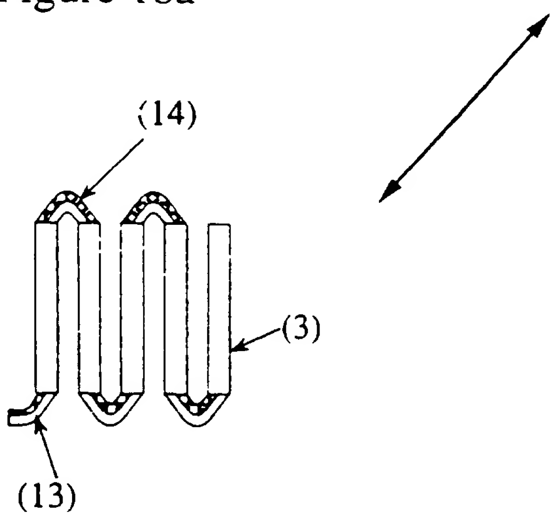


Figure 18b

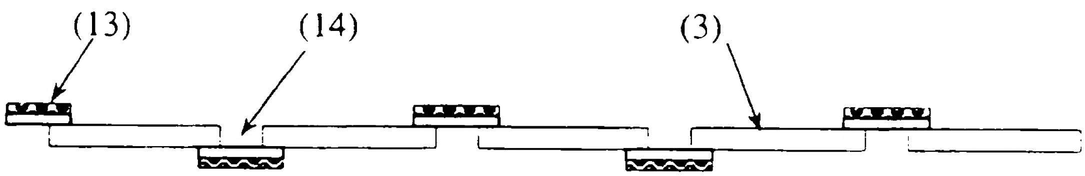


Figure 19a

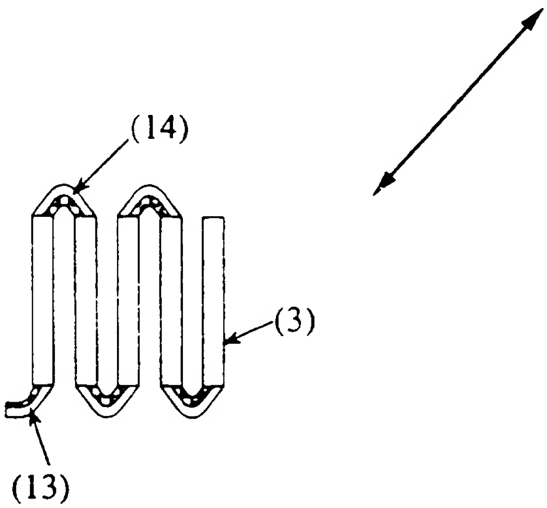


Figure 19b

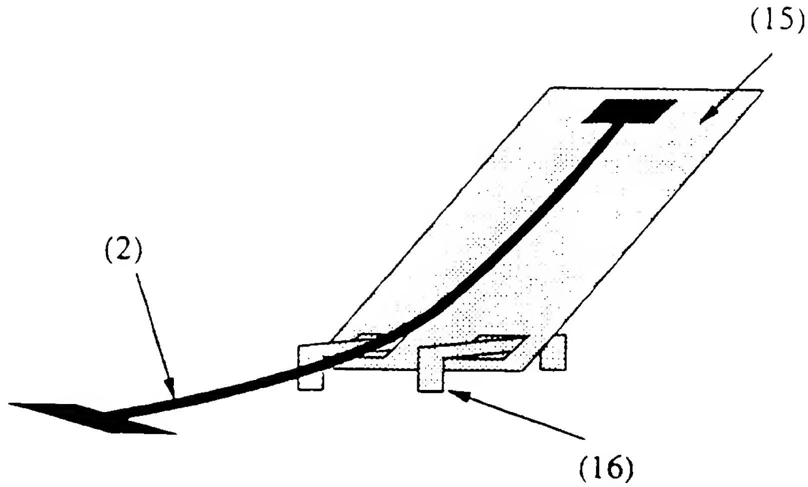


Figure 20a

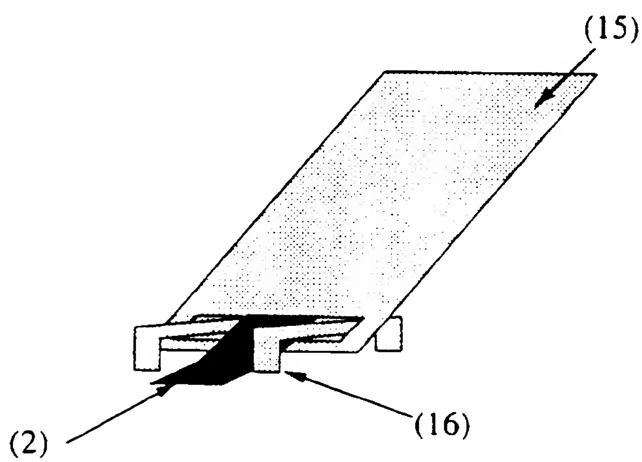


Figure 20b

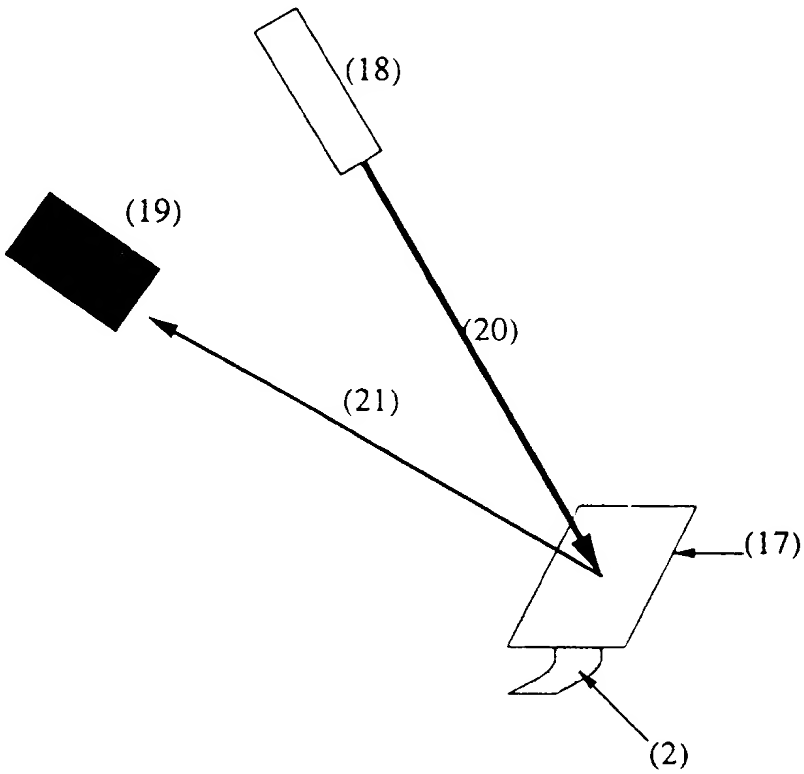


Fig. 21

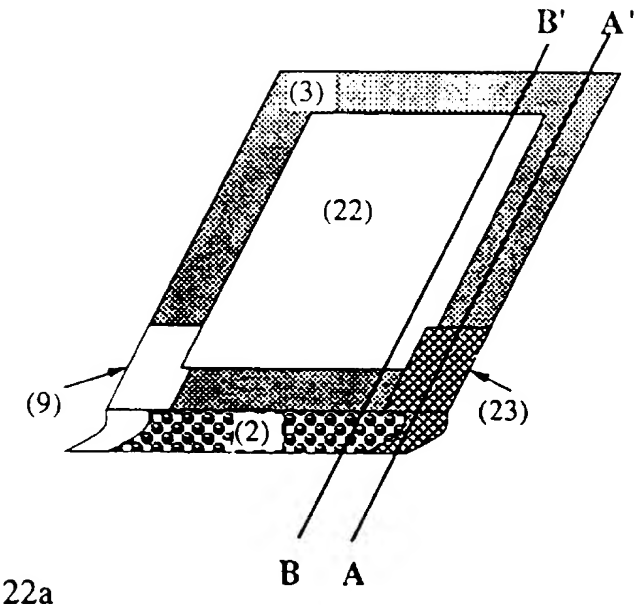


Fig. 22a

cross section A-A'

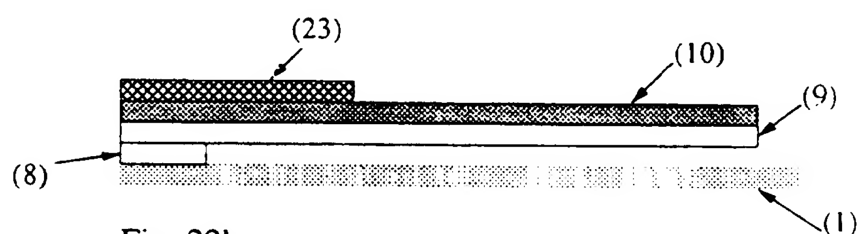


Fig. 22b

cross section B-B'

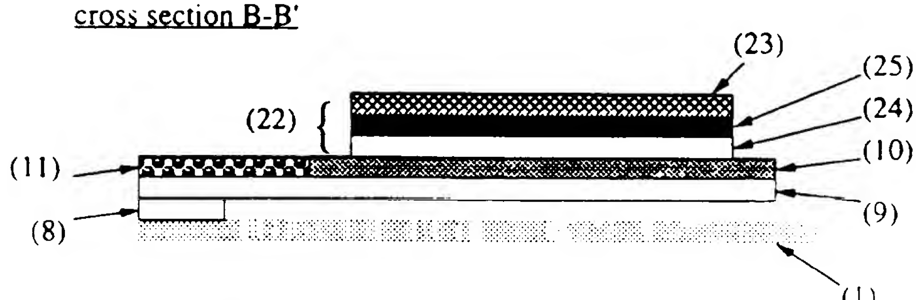


Fig. 22c

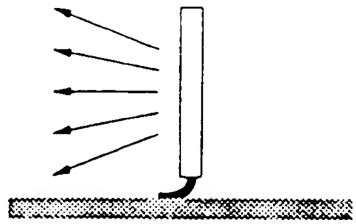


Fig. 22d

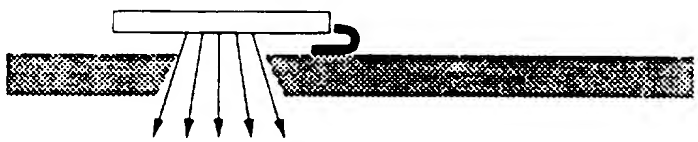


Fig. 22e

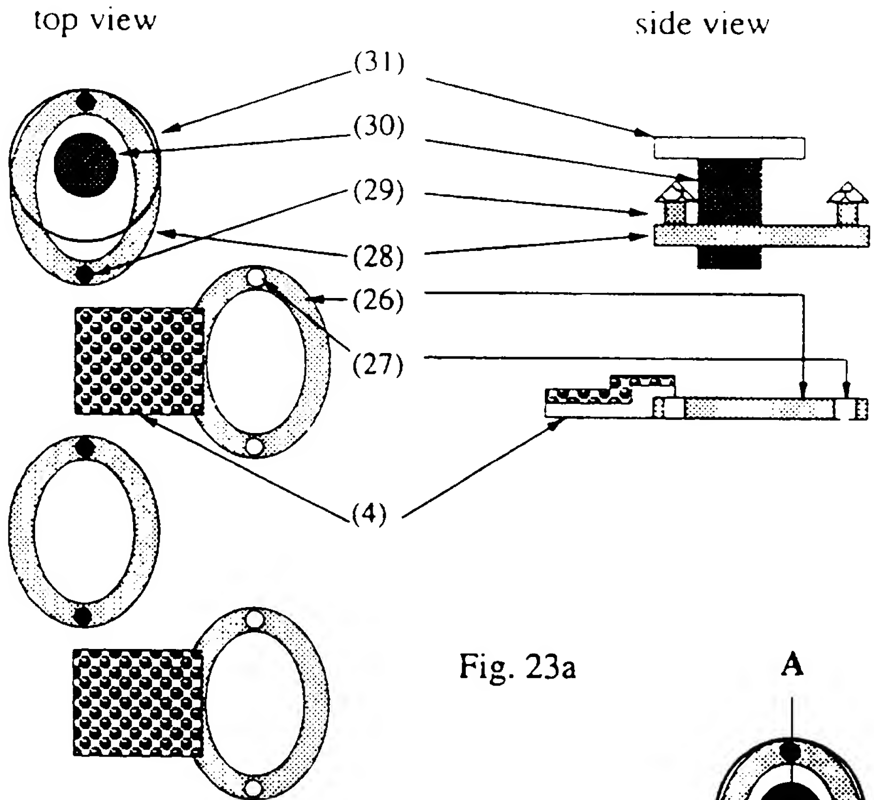


Fig. 23a

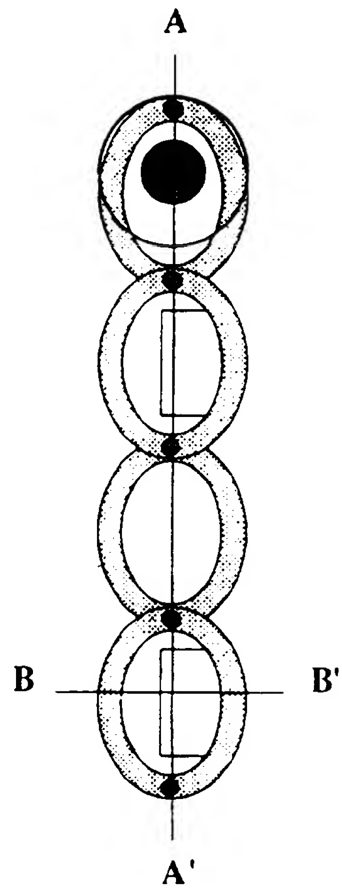


Fig. 23b

cross section A-A'

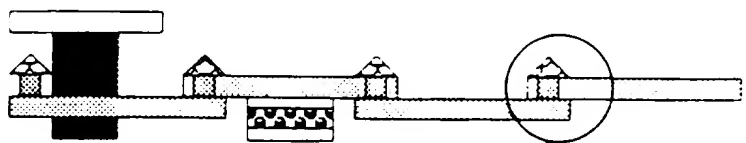


Fig. 23c

cross section B-B'

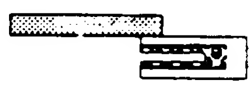


Fig. 23d

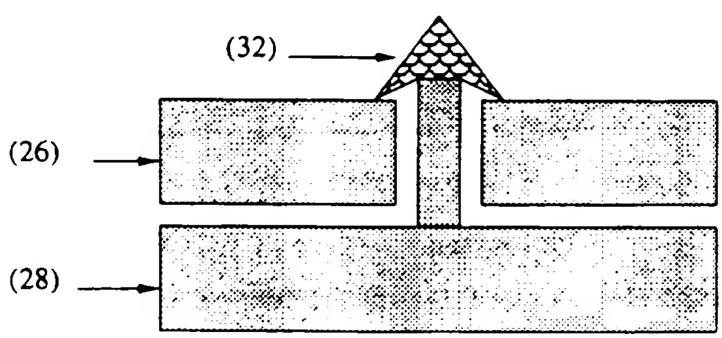
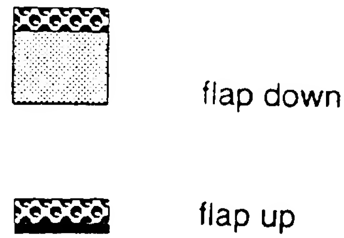


Fig. 23e



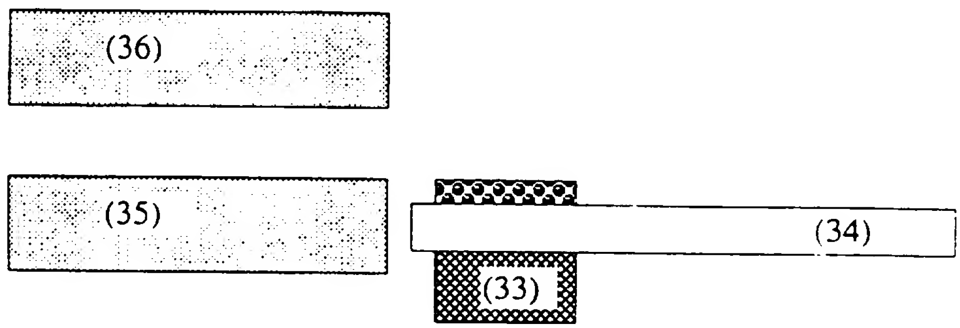


Fig 24a

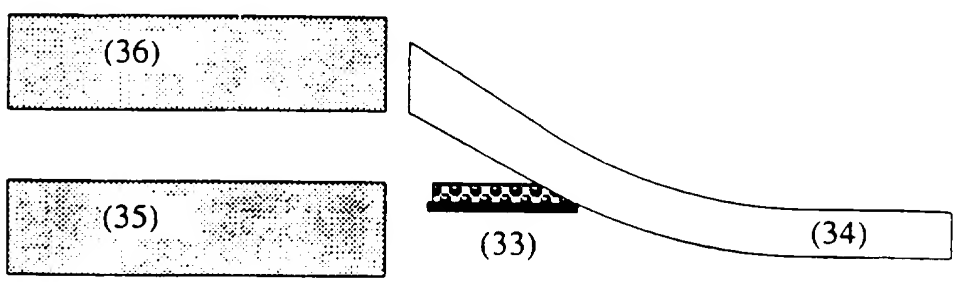


Fig 24b

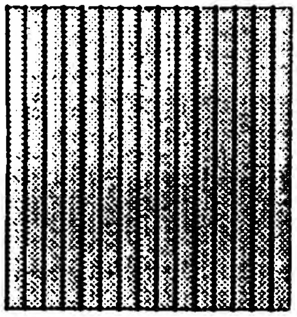


Fig 25a

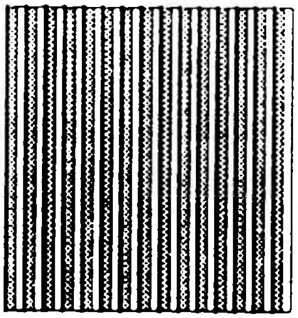


Fig 25b

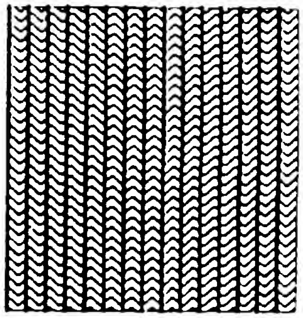


Fig 25c


Fig 25d

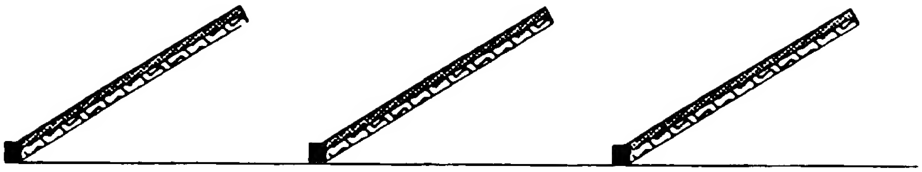


Fig 25e


Fig 25f

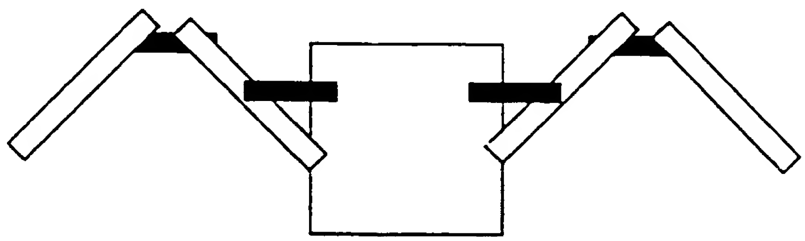


Fig 26

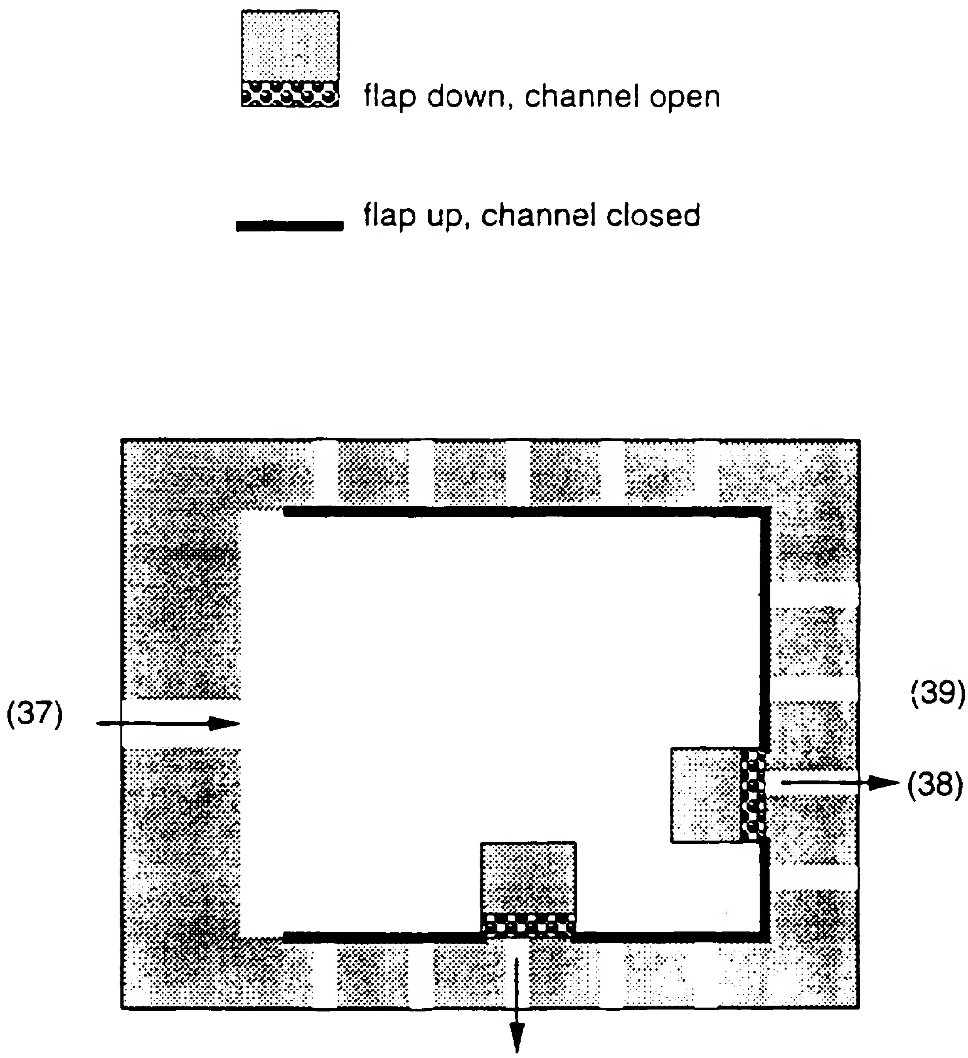


Fig 27

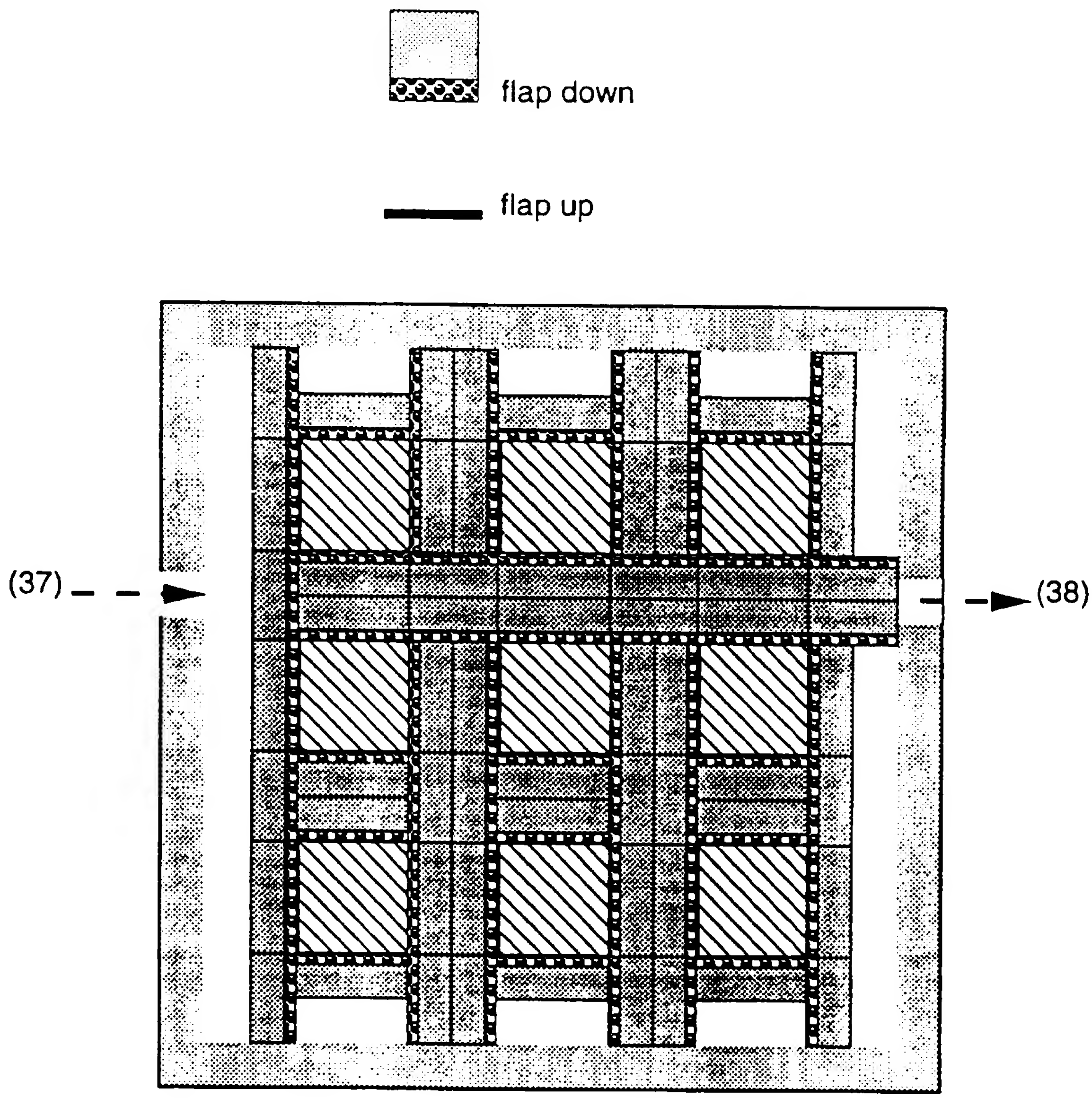


Fig 28a

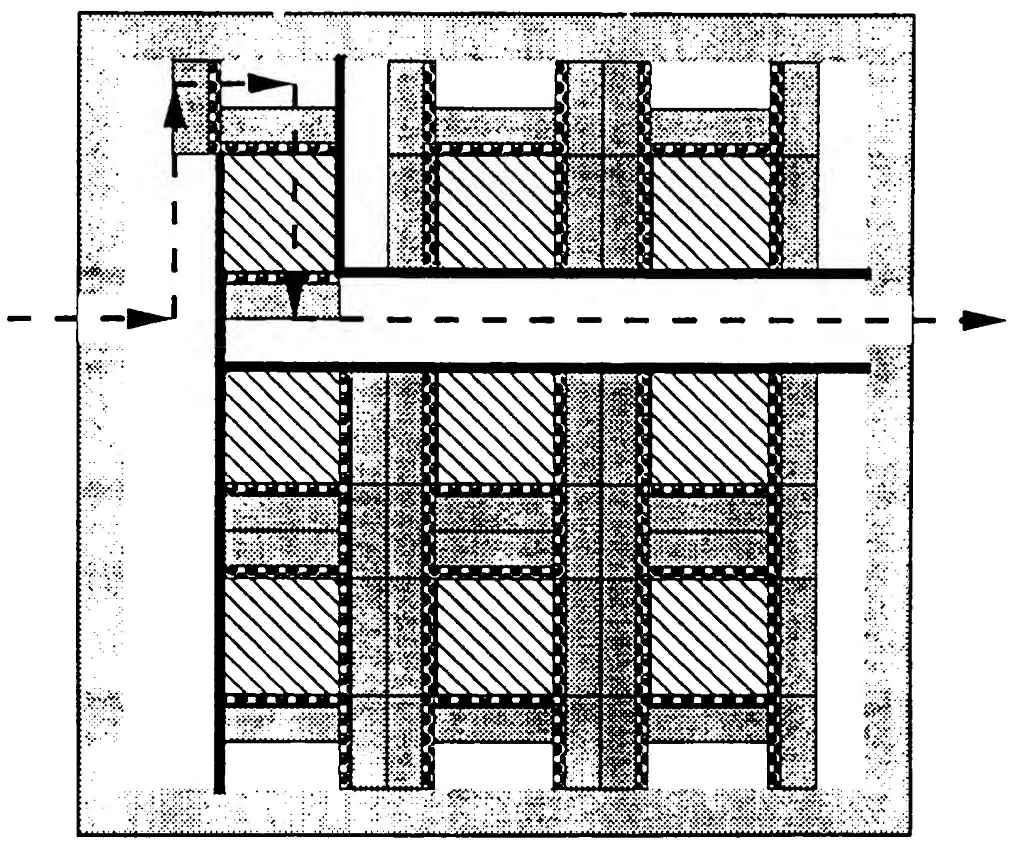


Fig 28b

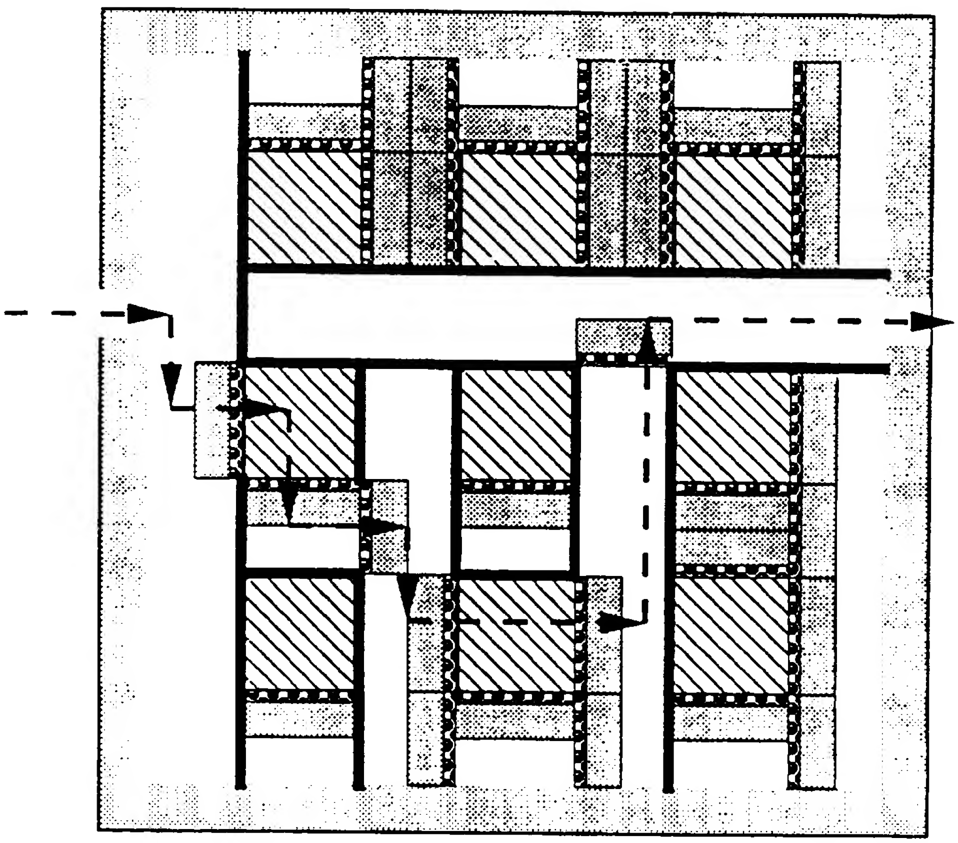


Fig 28c

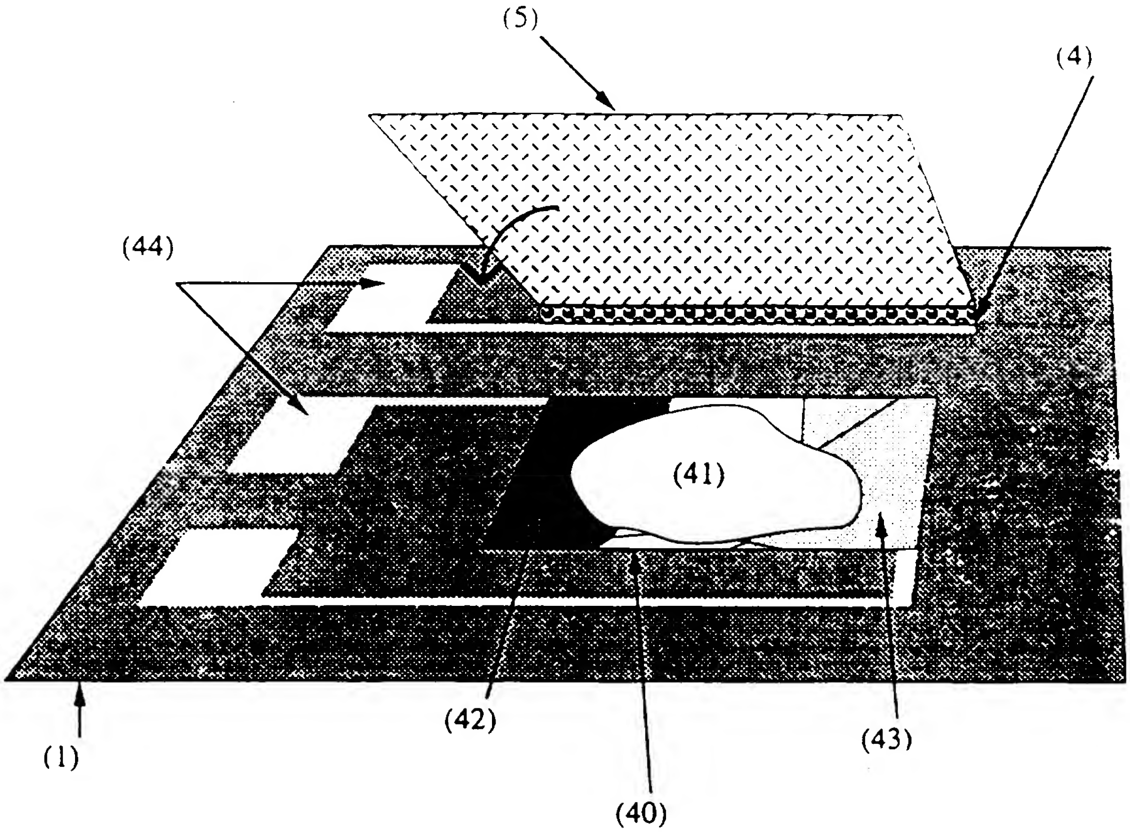


Fig. 29

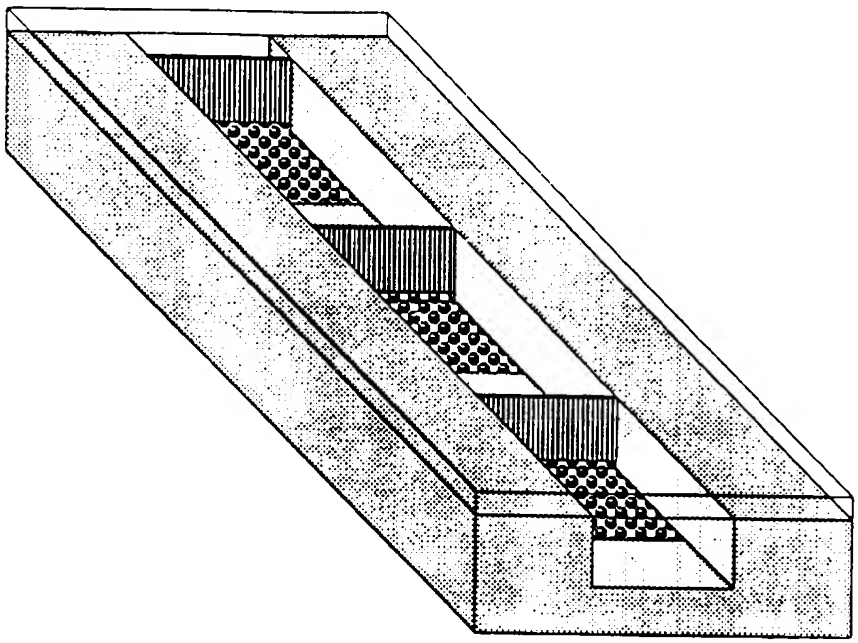


Fig. 30

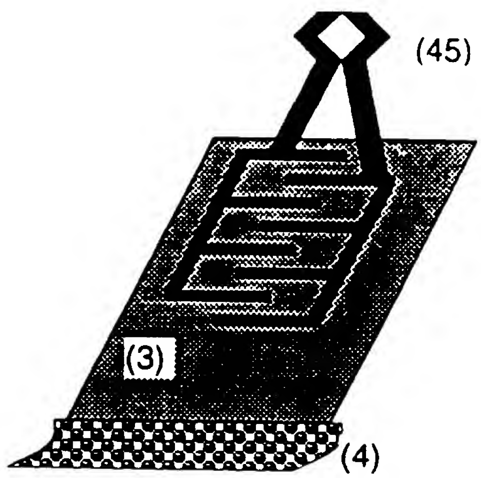


Fig 31

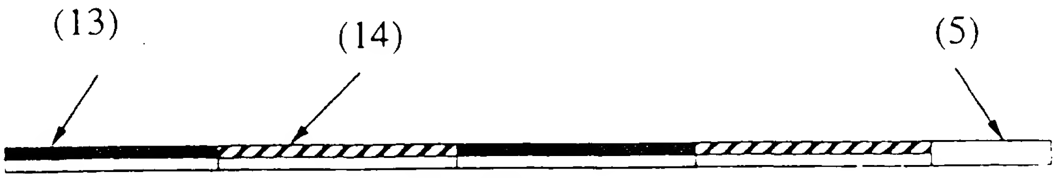


Fig 32a

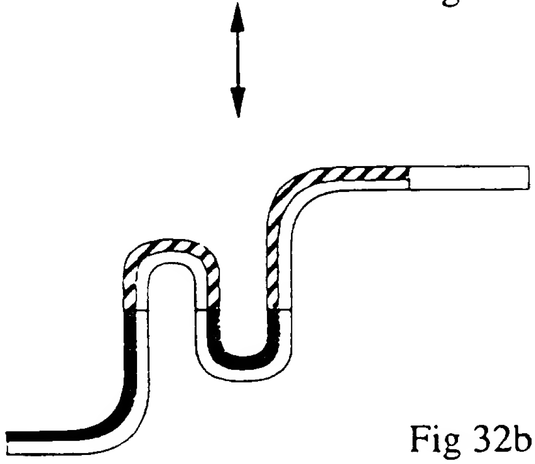


Fig 32b

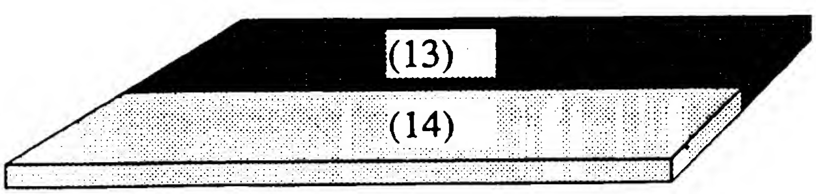


Fig 33a

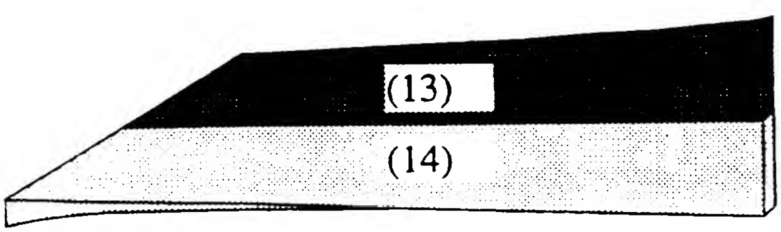


Fig 33b